THE UNIVERSITY OF ALABAMA

FOURTH SEMI-ANNUAL REPORT ON NsG-381

IN SUPPORT OF RESEARCH

IN THE AEROSPACE PHYSICAL SCIENCES

September 1, 1964 - February 28, 1965

UNIVERSITY, ALABAMA
May 10, 1965

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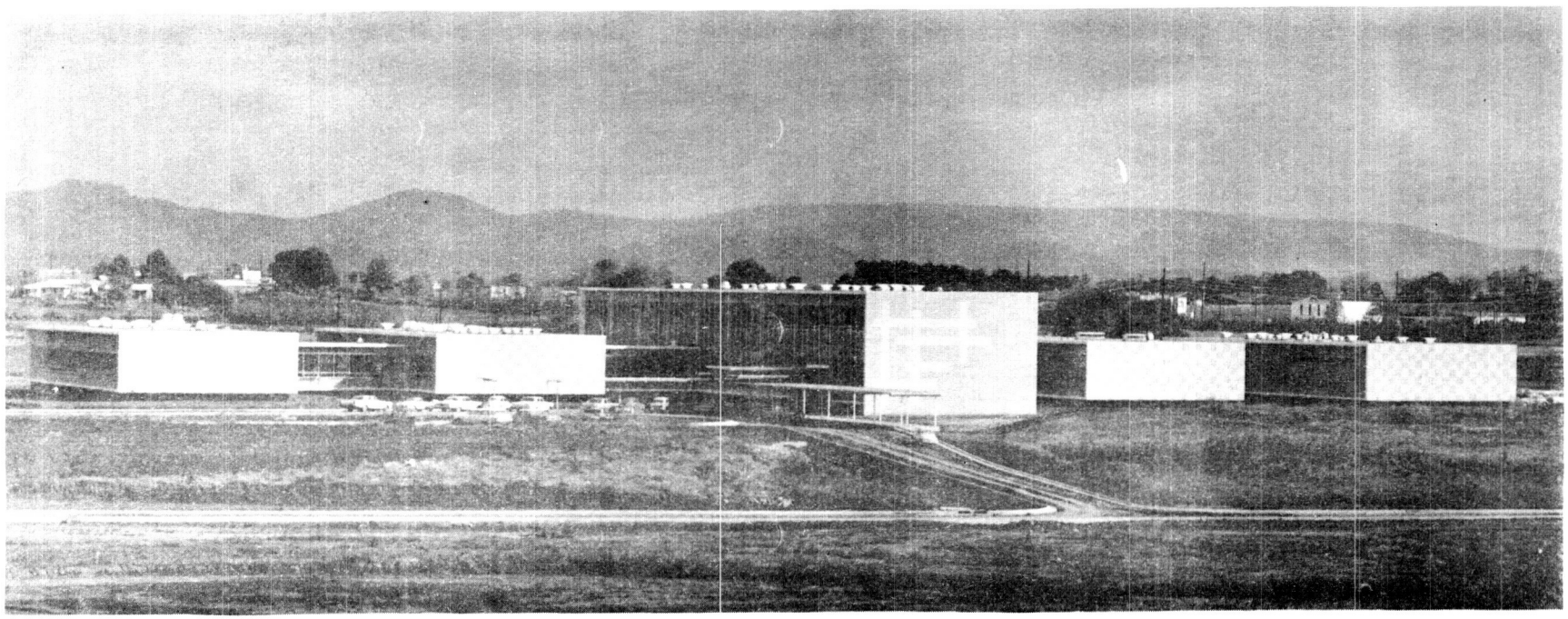

1.0 Introduction

This report outlines the efforts from September 1, 1964 to February 28, 1965 supported in full or in part by the National Aeronautics and Space Administration Grant NsG-381. Funds from the grant are used by the University of Alabama and its Research Institute to develop additional interdisciplinary research programs in the aerospace sciences and engineering. The work of the Research Institute is linked closely with the establishment of the resident master's degree program of the University of Alabama in Huntsville and the development of the desired academic atmosphere in Huntsville. Personnel, devoting at least a portion of their time to the research program, has increased steadily from a staff of 16 to 29, 44, 53, and 61 at the end of each six-month period since March 1, 1963 when the grant became effective. These figures have been adjusted from previous reports to remove the number of individuals who, until December 1, 1964, were funded partly by Univac and partly by the University of Alabama Research Institute, and who are no longer on the University payroll.

The Research Institute building, which has been beneficially occupied since June 16, 1964, was approved for final payment on January 21, 1965. Considerable effort has been expended during this semi-annual period in establishing the laboratories and placing equipment in an operating condition.

2.0 Status of Development of the University of Alabama Research Institute

2.1 Staff - The staff, selected for its ability to conduct an interdisciplinary research program in the aerospace physical sciences and engineering, have continued to grow during the six-month period from September 1, 1964 to February 28, 1965. The selection of staff for the research program is closely related to the development of graduate study opportunities in Huntsville and the establishment of the resident graduate program of the University of Alabama in Huntsville. On

September 1, 1964, at the end of eighteen months of operation since the availability of the National Aeronautics and Space Administration NsG-381 Grant, the academic and senior research staff of the University of Alabama in Huntsville in the physical sciences and engineering totaled thirteen people. On March 1, 1965, the academic and senior research staff in the physical sciences and engineering totaled twenty people. With the exception of five staff members, the total staff of the University of Alabama in Huntsville in the physical sciences and engineering has been engaged in research activities at the Research Institute. Two of the new staff members were completing publications started before coming to Huntsville, and one of the remaining staff members was engaged in writing a textbook during this period. This high percentage of participation emphasizes the effort that is being made to have the research and instructional programs complement each other, with each program benefiting by the dual participation, so that a graduate program of excellence can be established and maintained in Huntsville.

During the period September 1, 1964 to February 28, 1965, nine of the senior personnel devoted all or a portion of their time to the National Aeronautics and Space Administration NsG-381 Grant supported research. Seven additional academic staff members were supported by research grants or contracts from George C. Marshall Space Flight Center, Goddard Space Flight Center, or the U. S. Army Missile Command. Personnel previously engaged in research at the Research Institute and supported either in part or entirely by NsG-381 who have left the Research Institute during the six-month period were Dr. F. J. Tischer, Professor of Electrical Engineering, and Dr. A. A. Hayday, Associate Professor of Mechanical Engineering.

During the same six-month period three new members of the academic staff of the Research Institute worked on NsG-381 Grant. It is expected they will develop new research programs. These people were Dr. W. F. Arendale, Professor of Chemistry and Assistant Director of the Research Institute, Dr. R. L. Causey, Associate Professor of Mathematics, and Dr. Wilhelm Kubitza, Professor of Engineering Mechanics. In addition, Dr. G. A. Wempner, Professor of Engineering Mechanics,

Dr. J. T. Oden, Assistant Professor of Engineering Mechanics, and Dr. D. R. Jeng Assistant Professor of Mechanical Engineering, have been employed with full-time teaching loads. It is expected that they will contribute to the research program when they can be relieved from their teaching load. In addition to this academic staff, four research associates and five permanent professional employees devoted full-time to research. New research associates are Mr. C. F. Chen and Dr. J. C. Chang. New permanent professional employees are Mr. Manfred J. Loh, Aeronautical Research Engineer, and Mr. Henry Crenshaw, Physicist.

Also, ten research assistants (full-time graduate students) and three undergraduate assistants divide their time between research and classes. The academic and research staffs are supported by a full-time administrative, maintenance, and clerical staff of twenty. A total of sixty-one people devoted full time or part time to the activities of the Research Institute during February, 1965. This represents an increase of eight people, or 15%, over August 30, 1964. Statistics concerning the number of Research Institute personnel are shown on Table I. In the previous semi-annual report, ten people were listed as jointly funded by Univac Division of Sperry Rand Corporation and the University. These people were involved in the operation of Univac Computation Laboratory located in the Research Institute building. On December 1, 1964 Univac assumed full responsibility for its personnel, and they now report to the manager of the Univac Computation Laboratory. The University of Alabama Research Institute has staff members who are responsible for computer operation during the four hours each day allotted to the University. When University personnel are not available for programming or key-punching, time is purchased from Univac on a per hour arrangement. In general, the time is purchased on this basis until economics dictates that a full-time person can be supported by the Research Institute. Currently, the Research Institute's relationship with the Computation Laboratory is the responsibility of Dr. Robert L. Causey, Associate Professor of Mathematics and Head of the Computer Science Laboratory.

2.2 Facilities - Personnel at the University of Alabama in Huntsville working on research are located in the Research Institute building. The housing of all professional disciplines in one building strongly contributes to the development of interdisciplinary interest and brings to bear a forceful team effort upon problems of interest. The Research Institute building, provided by a $3,000,000 bond issue by the State of Alabama, was beneficially occupied on June 16, 1964. Final payment for the building was approved by the State Building Commission on January 21, 1965.

During the six-month period from September 1, 1964 to February 28, 1965, significant efforts of the staff have been directed toward establishing the laboratories and particularly in placing equipment in working order. Movable equipment, obtained from all sources of funding and valued at $298,119.53, was received during the twelve month period ending February 28, 1965. On March 1, 1965, the surface physics laboratory, two laboratories related to the study of microwave phenomena (one for transmission and the other for problems related to communication), and an optics laboratory were in operation. Upon his arrival on February 1, 1965, Dr. Wilhelm Kubitza initiated work to prepare the structural mechanics laboratory for studies in experimental stress analysis. In addition, floor space has been set aside for grouping the analytical instrumentation, such as spectrophotometers and a chromatograph, so that the equipment may be used as required. Some of this equipment will be moved to other laboratories from time to time when extended use is contemplated.

The establishment of the experimental program should contribute significantly to the total value of the research program, since the program has been previously limited primarily to theoretical investigations, pending availability of these new laboratory facilities. The enthusiastic reception of the new facilities indicates that even greater results than have been obtained in the past will be obtained in the future on research programs related to the missions of the National Aeronautics and Space Administration.

2.3 Academic Program - In the fall quarter, 1963, the resident master's degree program was established in Huntsville in mathematics, physics, and engineering with a major in mechanical engineering, electrical engineering, and engineering mechanics with three options, solid mechanics, fluid mechanics and dynamics, and vibrations. Beginning with the fall quarter, 1964, industrial engineering was added

to the resident master's degree program. Graduate courses are also available in aerospace engineering, chemical engineering, and metallurgical engineering. The opportunity to utilize the staff members of the Research Institute for instruction and direction of students in significant research for their theses in the physical sciences and engineering is an essential factor in the development of the resident master's degree program. The growth of the Research Institute is essential to the continued development of the master's program and, ultimately, to the resident Ph. D. program in Huntsville. To obtain the Ph. D., the requirement remains that a student must spend in residence at the Main Campus two semesters of the time required to earn the degree.

The number of courses offered for graduate credit and the number of students working on theses increased during the year. During the past academic year, 115 graduate courses were taught. This represents an increase of 44 classes or 62% over the previous year. The classes were attended by 1,701 students, an increase of 673 or 65% over the previous year. The enrollment in graduate work for the fall quarter 1964 was 774, an increase of 177 or 29% over the fall quarter a year earlier. During the winter quarter 1965 the graduate enrollment was 659.

The people of Huntsville and surrounding communities have exceeded their goal in a campaign to raise $750,000 to be used in connection with other funds to construct a new graduate classroom building. Cash pledges now constitute approximately $900,000. This is to be merged with money available to the University from non-Federal sources and with available Federal funds to construct a new classroom building adjacent to the Research Institute that will be used for the graduate instructional program. The laboratories for faculty and graduate student research necessarily associated with this new classroom building will be provided in the adjacent Research Institute. An application filed for a grant under the graduate academic facilities program for $420,900 for the new building has been approved. It is contemplated that the graduate faculty in aerospace related physical sciences and engineering will more than double during the next few years.

2.4 Seminars and Lectures by Visiting Speakers - During this six-month reporting period, the Research Institute has continued to bring to the campus outstanding

outside lecturers who contribute significantly to the enrichment of the research activities by providing additional stimulus to interdisciplinary activities. The eight lectures or seminars have been attended by an average of 60 people. A number of personnel from the George C. Marshall Space Flight Center, the U. S. Army Missile Command, and personnel of aerospace and missile related industrial contractors in the area attended these meetings. Listed in Appendix I are the speakers, their affiliation, title of the talk, and a short abstract of the presentation.

2.5 Research Funding - The Research Institute was organized on October 1, 1960. A National Aeronautics and Space Administration grant, NsG-381, starting March 1, 1963 was the stimulus for accelerated growth toward a staff capable of important research accomplishments. The $600,000 grant, with $300,000 allocated for the first year, $200,000 the second year, and $100,000 the third year, gave the assurance of continuity to the selected projects; provided the academic freedom for the investigation of basic problems; gave flexibility and choice of areas of research of interest to the National Aeronautics and Space Administration that were developed first; and relieved new staff members of the obligation to place primary emphasis on proposal writing and obtaining contracts before establishing the research program. The approval of the application for the second increment of funding of $300,000 ($100,000 per year for three years) at the beginning of the second grant year, March, 1964, allowed the Research Institute to expand its program on the same basis for a second year. The increase in research results is believed to be at least as great as the increase in expenditures for such research. The expenditures are shown graphically on Figure 1. During the past year, expenditures charged to NsG-381 have been roughly equal to those charged to other contracts and grants. During the period March 1, 1964 to February 28, 1965, in addition to the funds derived from NsG-381, funds were obtained from the George C. Marshall Space Flight Center as follows:

Contract No.	Title	Principal Investigator	Amount
NAS8-1646	Topological Dynamics	Dr. Hsin Chu	$24,974
NAS8-5411	Parameter Optimization	Dr. R. Hermann	47,162
NAS8-11231	Adaptive Control Theory	Dr. C.D. Johnson	16,792
NAS8-11249	Slow Electron Scattering	Dr. R.A. Mann	9,734
NAS8-2585	Surface Ionization	Dr. R.A. Mann	40,086
NAS8-11202	Earth Tremors	Mr. V.M. McCarty	59,286

and from Goddard Space Flight Center:

Contract No.	Title	Principal Investigator	Amount
NsG-608	Wave Propagation	Dr. F. J. Tischer & Mr. H. Y. Yee	$80,000

$57,449 of the $80,000 grant for the study of wave propagation through plasmas was cancelled due to termination of the grant on January 31, 1965, upon the termination of Dr. F. J. Tischer. (Continued work has been shifted to NsG-381 funds until further contracts are obtained). This is a total (after cancellation) of $220,585.

Contracts obtained from the U.S. Army Missile Command prior to March 1, 1965 were:

Contract No.	Title	Principal Investigator	Amount
DA-AMC-01-021- 64-G1	Microwave Propogation Microwave Detection	Dr. F. Mitchell Jr. Dr. R. J. Polge	$103,854
DA-01-009-AMC 164(Z)	Coherent Light	Dr. R.A. Mann	54,354
DA-01-009 AMC 165 (Z)	Automatic Control Theory	Dr. C.D. Johnson	35,299
DA-01-021 AMC 12093(Z)	Pointed Bodies	Dr. R. Hermann	20,768
DA-01-021 AMC 11870(Z)	Information Retrieval	Dr. Robert Causey	2,495

This represents a total of $216,770. It is estimated that a minimum of $500,000 in contracts and grants, exclusive of funds for National Aeronautics and Space Administration Grant NsG-381, will be available for the 1965-66 academic year. At this time, through personnel devoting their efforts to the Research Institute's program, the Research Institute has a capability in hypersonic aerodynamic research, including non-equilibrium flow around blunt and pointed bodies; electromagnetic phenomena, including communication theory and microwave transmission through wave guides and plasma; mathematics, including topological dynamics and numerical analysis; control theory; physics, including optics, nuclear, atomic, surface, and chemical physics.

2.6 Publications and Lectures - The personnel of the Research Institute have been active in making research results available to interested persons. Shown in Appendix II are the publications of personnel of the Research Institute that have appeared in technical journals in the past six months, that have been submitted for

publication and accepted,or are pending publication at this time. Each publication is shown with author, title, date or status of publication,and the short abstract that was published with the publication or has been provided for the purpose of this summary.

3.0 Research Activities

3.1 Summary of Activities During the Period September 1, 1964 to February 28, 1965

Funds derived by the University of Alabama Research Institute from the NsG-381 grant are used primarily to permit new staff members to establish the desired interdisciplinary programs in aerospace sciences and engineering. During the current six-month reporting period,these funds were used almost exclusively for this purpose. Dr. Juerg Kallweit was supported 100% by the grant. His work during the six-month period was related to the establishment of instrumentation of the optics laboratory. Some of the equipment was used in demonstrating the feasibility of an interferometric device for detection of the size of an object at a great distance. The most significant difference between this work and other work with interferometers is that the instrumental conditions required for the formation of interference fringes is considered rather than the fringe system. This method will not give the high precision usually associated with interferometers, but it does allow a simple and quick determination of the comparative size of neighboring objects with good accuracy. A differential interferometer has been placed in operation, and initial preparations have been made to measure the shape and temperature distribution of boundary layers of rotating bodies of revolution. These experiments are to be used to verify the theoretical results recently obtained by Dr. A. A. Hayday.

Mr. Chin-Fan Chen joined the staff of the Research Institute on November 1, 1964 and has been working with Dr. C.D. Johnson in the field of control theory. Mr. Chen has written papers (see Appendix II) and proposals concerning future work. During the four months of this reporting period that he has been a member of the staff,he has studied general methods of control system analysis with particular emphasis on the recent advances of Liapunov's stability theory.

Dr. R. L. Causey, Associate Professor of Mathematics, joined the staff on October 15, 1964,and has devoted approximately three-fourths of his time to research

efforts. Dr. Causey has been assigned responsibility for coordinating the relationship between the University of Alabama Research Institute's computer activities and the Univac Computation Laboratory. In addition, contracts have been received in response to Dr. Causey's proposals for work in his field of interest. He is now working on contracts with the U. S. Army Missile Command, DA 01-021-AMC-11870(Z) entitled "Application of Mathematics to Information Retrieval," with an effective date of February 16, 1965, and DA 01-021-AMC-11901(Z) entitled "Numerical Analysis of Methods for Computing Three Dimensional Supersonic Flow," with an effective date of March 5, 1965.

Dr. N.F. Audeh and Mr. H. Y. Yee, who have previously been working with Dr. F. J. Tischer on problems associated with electromagnetic wave propagation in groove guides, were supported approximately one-half time each on NsG-381 to develop research ideas in this subject. Mr. H. Y. Yee also previously had been working with Dr. F. J. Tischer on problems associated with electromagnetic wave propagation through plasmas, a subject which he is continuing to study.

Dr. W. R. Garrett has spent one-fourth of his effort on problems supported by NsG-381. Photo detachment and photo ionization cross sections in the infrared-visible and soft x-ray regions have been studied.

Since joining the Research Institute on September 1, 1964, Dr. Arendale has been engaged in organizing a program in chemical physics related to aerospace and missile-related programs. Progress has been made in planning instrumentation for the laboratories, and several proposals have been prepared. Proposals totaling $150,000 currently under consideration by the U. S. Army Missile Command, are related to the transmission, reflection, and absorption of monochromatic and coherent light. Dr. Arendale is interested in the properties, particularly the chemical activity, of excited molecules and ions. Additional consideration will be given to this work during the next six-month period.

A graduate student has been given partial support to work under the direction of Dr. C. P. Bhalla, Associate Professor of Physics, in order to initiate a program related to nuclear physics. The specific problem is related to the determination of electron radial functions.

Dr. A. A. Hayday, whose resignation became effective January 31, 1965, was supported for 60% of his effort during which time four papers were completed.

Miss Patricia Lucas, a graduate student, has also been given partial support while working with Dr. Hsin Chu. This work has been summarized in a paper that has been submitted for publication and is summarized in Appendix II.

Mr. B.R.K. Choudary, a student working with Dr. A.A. Hayday, was supported during this reporting period while he completed a master's thesis, "Combined Free and Forced Convection on a Spinning Cone in Laminar Boundary Layers."

Nine other students were given support while working on various research tasks of interest to the NsG-381 program.

3.2 Summaries of Current Interests of Staff Members - The primary interests of staff members of the University of Alabama Research Institute were recently summarized in Attachment A of "Application of the University of Alabama to the National Aeronautics and Space Administration for a Grant of $411,000 For Further Support of Research in the Aerospace Physical Sciences and Engineering February 25, 1965. These summaries are repeated as Appendix III of this report.

3.3 Programs Planned for the Next Six Months - The NsG-381 support will continue to be used to strengthen the University of Alabama program in the aerospace sciences and engineering.

3.3.1 Laboratory Development - The development of the experimental laboratories that was started during the last six months will be accelerated during the next six months. Although some experiments corresponding to the research interests of Dr. Juerg Kallweit, Dr. W. F. Arendale, Dr. W. K. Kubitza and Dr. J. C. Dowdle, as described in Appendix III, Sections G, H, N, and O, will be performed, a major portion of the effort of these people which is charged to NsG-381 will be directed to laboratory development.

3.3.2 Structural Mechanics - Dr. G. A. Wempner, Professor of Engineering Mechanics, and Dr. J. T. Oden, Assistant Professor of Engineering Mechanics, joined the faculty of the University of Alabama in Huntsville last September. Both have devoted full time to the instructional program and to writing initiated prior to joining the University of Alabama staff. During the next six months

period they will devote part time and possibly full time during the summer to their interest in structural mechanics as described in Appendix III, Section N.

3.3.3 Control Sciences - In addition to Mr. Chih-Fan Chen, Research Associate, Dr. David A. Ford, Mathematician, who will be employed for the summer, will work in the area of control theory defined in Appendix III, Section L.

3.3.4 Hypersonic High-Temperature Fluid Dynamics - Dr. J.J. Brainerd, Associate Professor of Aerospace Engineering, and Mr. Richard D. Wood, Research Associate, will join the organization on July 1, 1965. Dr. Brainerd, Mr. Wood, Mr. K. O. Thompson, and possibly others named in Appendix III, Section A, will be continuing the work concerning hypersonic high-temperature gas flow that has been a part of the Research Institute program from the beginning. The immediate plans are more completely described in Appendix III, Section A. Mr. Wood will also direct a portion of his time to efforts concerning the feasibility of a high-temperature gas dynamics laboratory and a space environment laboratory, considered as a possibility for component two of the Research Institute facilities.

3.3.5 Physics Programs - Dr. Chander Bhalla, Associate Professor of Physics, will allot a portion of his effort and that of a graduate student to the nuclear physics studies described in Appendix III, Section K. Dr. W.R. Garrett, Assistant Professor of Physics, for a portion of his effort will continue to pursue studies of atomic physics as described in Appendix III, Section I. Dr. W. F. Arendale, Professor of Chemistry and Assistant Director of the Research Institute, will devote a portion of his time to experiments in Chemical Physics described in Appendix III, Section H.

3.3.6 Microwave Transmission - Dr. N.F. Audeh, Associate Professor of Electrical Engineering, and Mr. H. Y. Yee, Research Associate, will devote approximately one-half time to studies concerning wave propagation in non-uniform plasma and to groove guide studies. Greater details of their interest have been described in Appendix III, Sections C and D.

4.0 Financial Report

4.1 Expenditures September 1, 1964,to February 28, 1965 - The financial report of funds spent from this grant is attached as Tables II and III. It should be noted

that Table II includes expenditures on the Tuscaloosa Campus. Expenditures at the Research Institute during the six-month period were $147,228.71. Administrative expenses during the period amounted to $72,436.71 of which $44,184.71 was provided by overhead on NASA Grant NsG-381.

Cumulative expenditures are as follows:

Expenditures March 1, 1963-February 28, 1964	$152,818.18
Expenditures March 1, 1964-February 28, 1965	331,761.55
Encumbrances and overhead as of February 28, 1965	73,694.86
	$558,274.59

4.2 Projected Effort March 1, 1965 to August 30, 1965 - The projects that the Research Institute expects to fund from NsG-381 during the fifth semi-annual period have been described in Section 3.3 Programs Planned for the Next Six-Month Period. It is expected that the funds will be distributed as follows:

3.3.1	Laboratory Development	$ 30,000
3.3.2	Structural Mechanics	20,000
3.3.3	Control Sciences	15,000
3.3.4	Hypersonic High-Temperature Fluid Dynamics	15,000
3.3.5	Physics Programs	30,000
3.3.6	Mircowave Transmission	15,000
	Overhead 20%	25,000
		$150,000

GRAPH OF EXPENDITURES - FIGURE 1

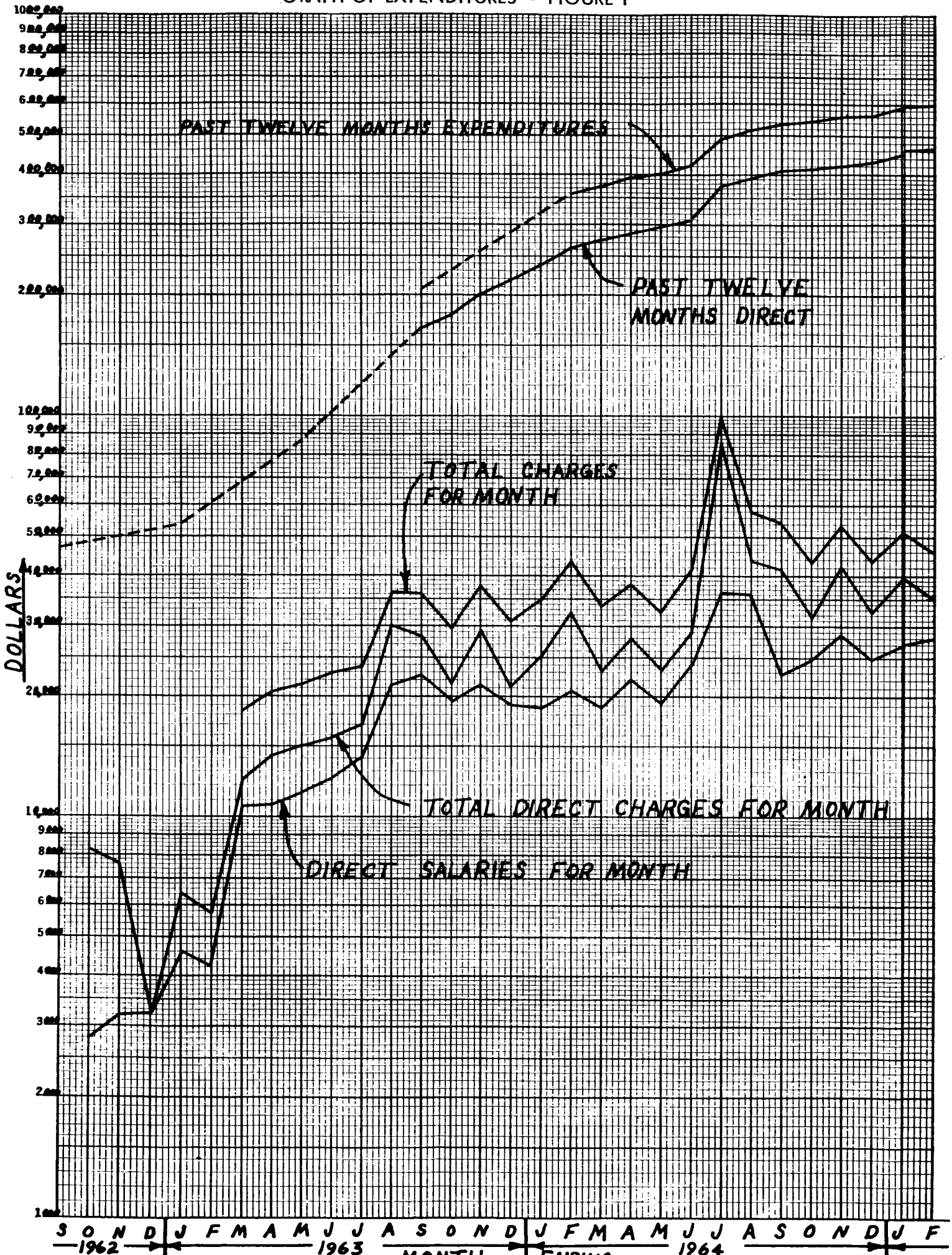

TABLE I

RESEARCH INSTITUTE PERSONNEL STATISTICS

A— Number of Permanent Staff, Including Part Time

	8/31/62	2/29/63	8/31/63	2/29/64	8/31/64	2/28/65
Academic	2	6	9	15	16	15
Permanent Research	0	0	4*	5*	6**	9
Plant Maintenance and Operations	0	0	0	0	5	7
Administration	4	6	8	13	12	13
Technical Service	2	2	2	2	4	4
Research Assistants (Graduate)	1	2	4	7	8	10
Undergraduate Assistants	0	0	2	2	2	3
Totals	9	16	29	44	53	61

* Excludes 1 person jointly funded with the Univac Division of Sperry Rand Corporation.

** Excludes 10 persons jointly funded with Univac.

B — Number of Summer Students

	1963	1964
Research Assistants (Graduate)	1	3
Undergraduate Assistants	6	10
Totals	7	13

TABLE II

UNIVERSITY OF ALABAMA RESEARCH INSTITUTE
Semi-Annual Statement of Expenditures and Encumbrances
For Period September 1, 1964 through February 28, 1965
NASA Research Grant NsG-381
and Supplement No. 1

Salaries		
Professional	$ 71,985.03	
Student	13,028.26	
Supporting Services	8,948.36	$93,961.65
Supplies		2,422.99
Travel and Communication		5,294.30
General Expense		11,893.76
Equipment		27,401.11
Total Expenditures		$140,973.81
Indirect Costs: 25% of Direct Costs ($117,782.97)		29,445.74
Indirect Costs: 20% of Direct Costs ($ 23,190.84)*		4,638.17
		$175,057.72
Plus Encumbrances		
Equipment on Order		58,955.89
Indirect Costs: 25% on Encumbered Items		14,738.97
Total Expenditures and Encumbrances		$248,752.58

*This amount expended during this period for Supplement No. 1 on Tuscaloosa Campus

Chemistry - Tuscaloosa Campus

Salaries		
Professional	$4,099.98	
Student	1,666.62	$ 5,766.60
Supplies		74.30
		$ 5,840.90
Indirect Costs: 20% of Direct Costs		1,168.18
		$ 7,009.08

Physics - Tuscaloosa Campus

Salaries, Professional	$ 3,250.00
Indirect Costs: 20% of Direct Costs	650.00
	$ 3,900.00

TABLE II (continued)

UNIVERSITY OF ALABAMA RESEARCH INSTITUTE
Semi-Annual Statement of Expenditures and Encumbrances
For Period September 1, 1964 through February 28, 1965
NASA Research Grant NsG-381
and Supplement No. 1
(Continued)

Mathematics - Tuscaloosa Campus

Salaries, Professional		$ 5,333.28
Indirect Costs: 20% of Direct Costs		1,066.66
		$ 6,399.94

Electrical Engineering - Tuscaloosa Campus

Salaries		
Professional	$6,833.34	
Student	1,933.32	$ 8,766.66
Indirect Costs: 20% of Direct Costs		1,753.33
		$10,519.99

I certify that this statement of expenditures and encumbrances is correct and in accordance with the terms of the grant.

Luther C. Callahan
Comptroller

TABLE III

UNIVERSITY OF ALABAMA RESEARCH INSTITUTE
Semi-Annual Statement of Expenditures
September 1, 1964, through February 28, 1965
(Administrative Portion)

Salaries		
Administrative	$43,902.47	
General Labor	4,822.20	$48,724.67
Supplies		4,311.43
Communication		4,670.73
Travel		731.61
Utilities		8,603.96
Repairs and Alterations		330.03
General Expenses		5,064.28
		$72,436.71

NOTE: These expenditures are provided for by the $44,184.71 in overhead on NASA Grant NsG-381 for this period and overhead received on other contracts and grants which the University of Alabama Research Institute has with governmental agencies.

I certify that this statement
of expenditures is correct.

Luther C. Callahan
Comptroller

APPENDIX I

University of Alabama Research Institute Seminars and Lectures

Mr. Edmund Stollenwerk, Senior Research & Development Scientist, Lockheed-California Company, Burbank, California. Lecture given November 9, 1964 with 26 persons in attendance.

Advanced Gas Dynamics and Altitude Environment Facilities

The lecture included a discussion of the types of advanced gas dynamics and altitude environment facilities which should be built and the reasons for their need, design, construction, cost, operation and the obsolescence anticipated. A description was given of Lockheed's new gas dynamics and environment facilities.

Dr. Roger Broucke, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California. Lecture given November 16, 1964 with 35 persons in attendance.

Classification of Periodic Orbits in the Restricted Three Body Problem with Earth and Moon Masses

The general goal of this study was to investigate flight mechanics in a simplified earth-moon system represented by the restri cted three body problem. But one of the first particular goals was the classification of a kind of orbits which plays a very special role: symmetric periodic orbits. About a thousand periodic orbits have been found and classified in about fifty families with the aid of automatic digital computer programs. Many families have unexpected characteristics, and several orbits have astronautical interests. The lecture developed a few general conclusions about the different orbits.

Dr. Arnold H. Kritz, Staff Scientist, Space Science Laboratory, General Dynamics, San Diego, California. Lecture given November 23, 1964 with 32 persons in attendance.

The Interaction of Electromagnetic Waves With Inhomogeneous Plasmas

Attempts to obtain diagnostic information concerning charge distribution in ionized media are often made by employing microwave techniques. These techniques were discussed. The theory employed in interpreting the diagnostic data must be sufficiently accurate so that the information inferred is reliable. Improvements in the theory applied to microwave scatter by ionized wakes of hypervelocity projectiles were discussed. The effects of finite wake radius relative to Fresnel zone thickness, microwave horn patterns, dipole radiation pattern of electrons and projectile displacement from ballistic range axis were all considered.

Mr. B. H. Shirley, Research Engineer, Senior, Lockheed Missile & Space Company, Huntsville, Alabama. Lecture given on December 8, 1964, with 28 persons in attendance.

Use of Liquid Hydrogen Cryopumping for Flow Rarefaction And Boundary Layer Control in a Low Density Nozzle

A method for controlling the growth of boundary layers in a low density hypersonic nozzle by actual mass transfer of the boundary layer fluid to the walls of the nozzle through the use of liquid hydrogen cryopumping was presented. Experimental data were shown to verify the conversion of merged boundary layer flows at $T_o = 300^o$ K, to core flows with a 50% increase in Mach number. The economics and techniques involved in the use of liquid hydrogen were discussed. The feasibility and efficiency of this method at high stagnation temperatures, to 4000^o K, were presented.

Mr. Kurt R. Stehling, Assistant to the President for Astronautics, Washington, D. C. Operations of Electro-Optical Systems, Inc. Lecture given on December 18, 1964, with 126 in attendance.

A Summary of Laser Technology As a Particular Application of Quantum Electronics

Stress was given to some of the latest pumping techniques and developments in injection lasers. Applications in the area of medicine, space tracking and communications, and possible military uses were reviewed.

Dr. Hermann Statz, an Assistant Manager of the Research Division of Raytheon Company, Waltham, Massachusetts. Lecture given January 12, 1965, with 136 in attendance.

Recent Developments in Lasers

The present state of the laser field was discussed. Conventional solid-state semiconductor, and gas lasers were considered. In the solid-state laser, emphasis was placed on the mechanisms responsible for multimode operation and spiking; and techniques were discussed which make spikeless single-mode operation possible. In the semiconductor field, injection lasers and electron beam excited devices were presented. Methods were discussed which enhance the spectral purity of these devices. In the gas laser field, special emphasis was placed on the new high-power ionized rare gas lasers. Mechanisms of operation were given, and in particular, a gas laser design was described which has already yielded continuous wave power outputs in excess of 6 watts in the visible region. Some discussion was given of low noise gaseous amplifiers.

Dr. Sven R. Hartmann, Assistant Professor of Physics, Columbia University, New York. Lecture given January 21, 1965, with 35 in attendance.

Photon Echoes

A description of spin echoes was presented using a simple vector model. The optical frequency analogue to the spin echo experiment was discussed, and equations of motion were obtained which are similar to those used to describe spin echoes. Numerical estimates were made for important parameters involved in the photon echo experiment, and several experiments were discussed which demonstrate the existence of the photon echo.

Dr. S. P. S. Porto, Quantum Electronics Research Department, Bell Telephone Laboratories, Murray Hill, New Jersey. Lecture given on February 12, 1965, with 63 in attendance.

The Use of the Laser as a Raman Source

The unique properties of the laser, i.e., its directionality, high monochromaticity, linear polarization of the light beam and its coherence make it an unusual light source. The use of both the ruby and red He-Ne lasers as Raman sources was discussed. Due to the difference of properties between the laser and the mercury discharge lamps, the problems of sample geometry for the observation of Raman effect require considerable thought and were considered in detail. The continuous photo-electric recording of the Raman effect was described. Some new properties of the Raman effect itself were discussed, and a "status of the art" report was made in the case of solid, liquids, and gases.

APPENDIX II

Publications of University of Alabama Research Institute Staff Members

(Publications are listed irrespective of source of support)

A. Papers published during September 1, 1964 to February 28, 1965:

C. P. Bhalla, "Ratio of C_A and C_V in Nuclear Beta Decay," Bulletin, American Physical Society, Vol. 10, page 544 (1965).

Abstract: Calculations have been completed on the ft-values of $0^+ \rightarrow 0^+$ transitions, using the accurate experimental data of Freeman et. al. Exact calculations of Fermi functions are made. Effects arising from finite nuclear-size-effects and finite nuclear de Broglie wavelength are considered. Furthermore, atomic screening effects are incorporated by using the Hartree-Fock self-consistent potential in the numerical solution of Dirac equation. Numerical results for the ratio of C_A and C_V are presented.

C. P. Bhalla, "Second-Order Effects in the Positron Decay in Co^{56} ($4^+ \rightarrow 4^+$)," Bulletin, American Physical Society, Volume 10, page 21, (1965).

Abstract: The energy dependence of the positron shape-factor, reported by the Langer group as $(1 + b/W)$, is analyzed by the inclusion of the contribution from the second-forbidden matrix elements and the finite-nuclear size effects. It is concluded that several satisfactory theoretical fits to the experimental data can be obtained within the framework of the V - A theory. This is similar to the results obtained for the electron decay in In^{114} ($1^+ \rightarrow 0^+$) and the positron decay in Zr^{89} ($\frac{9^+}{2} \rightarrow \frac{9^+}{2}$). Results will be presented.

Hsin Chu and Shoshichi Kobayashi, "The Automorphism Group of a Geometric Structure," Transactions of the American Mathematical Society, Volume 113, Number 1, pp. 141-150, October, 1964.

Abstract: Given a geometric structure on a manifold M, the group of transformations of M, leaving the structure invariant, is often a Lie transformation group. In this report, a historical account of such cases and systematic proofs of those results are given. In Part 1 we summarize known results in the chronological order and in part 2 we show how to derive them from a theorem of Palais. We also give a self-contained proof of the result of Palais as it is not easy to pick up the proof from this long paper.

W. R. Garrett and R. A. Mann, "Perturbation Calculation of the Interaction Potential for Atomic Scattering of Low-Energy Electrons," Bulletin, American Physical Society, Volume 10, page 128, (1965)

Abstract: Recent investigations of low-energy electron scattering from alkali atoms have shown the importance of the polarization term in the total atomic-scattering potential. In previous work, it was found that the use of a simple model, which represents the polarization potential in the scattering interaction, could yield calculated cross sections that agree well with available experimental data. In the present work, the polarization potential in the scattering interaction is calculated by considering the first-order perturbation of a Hartree-Fock-Slater atomic system caused by the incident charged particle in the adiabatic approximation. The method, which is analogous to the polarized orbital method of Temkin, yields a polarization potential that is similar in shape to the simple model used earlier; has an asymptotic value that agrees well with that yielded by the experimental polarizability α; and yields scattering cross sections that agree well with experimental data.

Rudolf Hermann and Janardanarao Yalamanchili, "Hypersonic Flow With Non-Equilibrium Dissociation ~~Around~~ Blunt Bodies in Flow Facilities and in Free Flight," presented at the annual meeting of the Wissenschaftliche Gesellschaft ~~fuer~~ Luft-~~und~~ Raumfahrt at Munich, Germany, October 8-12, 1963. Published in WGLR-1963-Yearbook, ~~pages 242-250.~~

Abstract: The first part is a theoretical determination of the steady, inviscid flow field in a hypersonic wind tunnel under non-equilibrium dissociation conditions. The second part of the investigation is concerned with the determination of the hypersonic non-equilibrium flow past a blunt body with the direct method.

The nozzle flow calculations reveal that, for the considered range of supply conditions, the flow is chemically frozen immediately downstream of the throat. When compared with equilibrium flow, this fact has a significant effect on temperature, density and Mach number distribution.

Various authors have solved the blunt body problem for air as a perfect gas using the general integral method developed by Belotserkovskii. The shock shape is determined by calculation, in contrast to the inverse method in which a shock shape is assumed. Belotserkovskii's method is used in this investigation to determine the non-equilibrium flow of dissociated air around a circular cylinder. It is for the first time, to the author's knowledge, that this method has been applied to a non-perfect gas.

The numerical calculations are carried out for a particular value (0.70) of frozen free-stream dissociation in the hypersonic wind tunnel.

Janardanarao Yalamanchili and Rudolf Hermann, "Non-Equilibrium Hypersonic Flow of Air in Hypersonic Nozzles and Around Blunt Bodies," presented at the Fifth International Symposium on Space Technology and Science, Tokyo, 1963, published in proceedings of the Symposium.

Abstract: Non-equilibrium hypersonic nozzle flow of air is investigated for supply temperatures of 4000 to 6000° K, supply pressures of 10 to 100 atm and for nozzle area ratios of 1 to 10,000.

The direct method is used for the first time to calculate the non-equilibrium hypersonic flow of air around blunt bodies. Results are given for the flow around a circular cylinder.

C. D. Johnson and J. E. Gibson, "Optimal Control With Quadratic Performance Index and Fixed Terminal Time," IEEE Transactions on Automatic Control, Volume AC-9, Number 4, pages 355-360, October, 1964.

Abstract: The conventional solution for the optimal control of a linear-stationary regulator with quadratic performance index and fixed terminal time leads to a linear control law with time-varying gain coefficients. In addition to the usual disadvantages of time-variable controllers, some of the time-varying gain coefficients approach infinity as the specified terminal time is approached.

In the present paper, it is shown that the optimal control for the above problem can be expressed in the form of a time-invariant non-linear control law. Certain parameters in the nonlinear control law are functions of the initial time and initial state of the system. The conventional time-varying linear control law can be obtained directly from the time-invariant nonlinear control law.

The results of the present paper are applicable to a more general class of optimal control problems involving linear and nonlinear systems. Two examples are given to illustrate the method.

J. H. Kallweit, "D C Conductivity of Porous Foils of Plastics," Kunststoffe 55 (1965), page 25.

Abstract: The properties of porous foils of polyvinylchloride as dielectric material in capacitors was checked by measuring the charging and discharging currents as function of time, temperature and electric field strength. Strong pol rization effects were observed. The resulting polarization potentials can reach the order of the applied potential. The discharging current of function of time can be described with the help of after-effect function of K. W. Wagner. The distribution function of relaxation times were derived.

F. H. Mitchell, Jr. and F. J. Tischer, "Partial Wave Analysis of Electromagnetic Wave Propagation in Inhomogeneous Media," presented by Dr. Mitchell to Southeastern Section of American Physical Society, November, 1964, and published as University of Alabama Research Institute Report #18, November, 1964.

Abstract: The basic wave propagation equations are derived for radiation from, and scattering off of, a plasma-clad conductor. A perturbation technique for handling inhomogeneous plasmas is described in detail and applied to the wave equations.

T. D. Shockley, "Radiation Fields of a Loop Antenna," Proceedings of the IEEE, Volume 52, Number 8, August, 1964.

Abstract: (not available)

William Gray, under the supervision of Dr. Hsin Chu, completed his Ph. D. Thesis, "Transformation Groups with Fixed End Point," at the University of Alabama, University, Alabama.

B. Papers accepted for publication during September 1, 1964 to February 28, 1965:

R. Douglas Archer and Rudolf Hermann, "Supersonic & Hypersonic Flow of an Ideal Gas Around an Elliptic Nose," AIAA Journal, Vol. 3, Technical Notes, May 1965.

Abstract: A solution is given for the steady flow field of a perfect gas around a two-dimensional elliptic cylinder in an inviscid supersonic free stream. The direct method of Dorodnitsyn and Belotserkovskii has been applied to the inviscid equations of the mixed subsonic-supersonic flow in the shock layer for the general case of a blunt body of any convex shape having continuous curvature. Results of first order theory are presented for a wide range of elliptic shapes and Mach numbers. An explicit form of the equations for infinite Mach number was obtained suitable for numerical calculations. A comparison of the first order theory and experiment in a hypersonic wind tunnel has been made at a Mach number of 6.8 for the case of an elliptic section in which the ratio of major to minor axis is 5, showing very satisfactory agreement.

N. F. Audeh and H. Y. Yee, "On Dielectric Lenses," to appear in Proceedings of IEEE.

Abstract: When horns are used for launching electromagnetic waves in parallel plane guides, fringing is inevitably introduced due to the horn walls. A dielectric lens may be used to correct this difficulty. The shape of the lens is determined by the fact that the electrical distance traveled through the air plus that traveled through the lens is constant.

C. P. Bhalla, "Positron Shape-Factor of Co^{56} $(4+ \rightarrow 4+)$," to appear in Nuclear Physics.

Abstract: Experimental beta-shape factor of Co^{56} $(4^+ \rightarrow 4^+)$, as reported to be represented by $(1 + b/W)$ by Hamilton, Langer, and Smith, has been analyzed by the inclusion of the second-order effects. Within the framework of the V - A theory, several excellent fits to the experimental positron shape-factor are obtained; thus, the need for a large P interaction and/or for the Uhlenbeck-Konopinski gradient coupling is unnecessary.

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C. F. Chen, "A New Rule for Drawing the Root Loci of Systems with Complex Roots," IEEE Transactions on Automatic Control, to appear July, 1965

Abstract: A new rule for constructing the root loci of a system with complex roots is developed. The procedure is deduced from Evans formula and is presented in a graphical form. An iteration method for finding the value of the break-away point is also included.

C. F. Chen, "Obtaining System Performance Measures from Routh's Algorithm," Proceedings of the IEEE, to appear April, 1965

Abstract: A Kalman-Bertram's Liapunov function is obtained by using the first Column of Routh's array only. Parks' and Swartz' formulations are simplified. The technique can be applied to evaluating the performance measures.

C. F. Chen and B. L. Philip, "Accurate Determination of Complex Root Transfer Functions from Frequency Response Data," to be presented at the Joint Automatic Control Conference, Troy, New York, June 22-25, 1965.

Abstract: This paper presents a method for determining the transfer functions coefficients of a system from its frequency response. The method is based on Bush's transfer function decomposition technique, and Chen-Shen's response conversion formula. It involves no prejudgement and, therefore, has no cumulative error.

Hsin Chu, "Fixed Points in a Transformation Group," to appear in the Pacific Journal of Mathematics.

Abstract: Professor A. D. Wallace proved the following: "Let (X, Z, π) be a transfomation group, where Z = the discrete additive group of all integers. If X is a Peano continuum with a fixed end point under Z, then Z has another fixed point." An interesting question has been raised by Wallace: "Can one reach the same conclusion about either compact groups or abelian groups?" In the case of compact groups, Professor H. C. Wang answered the question in the affirmative. We also give an affirmative answer to the question in the case of abelian groups when the abelian group is of the type either $R^n \cdot K$ or $Z \cdot R^n \cdot K$ where R^n is a vector group of dimension n and k is a compact abelian group. Actually, we also cover the case of non-abelian groups. The same conclusion can be reached if the group G is one of the following two types: (1) It contains a subgroup R^n such that G/R^n is compact or (2) It contains a subgroup $Z \cdot R^n$ such that $G(Z \cdot R^n)$ is compact.

Hsin Chu, "A Note on Compact Transformation Groups With a Fixed End Point," to appear in Proceedings of the American Mathematical Society.

Abstract: Professor A. D. Wallace proved the following: "Let T be a cyclic transformation group of a Peano continuum X leaving fixed an end point, then T has another fixed point." Professor H. C. Wang arrived at the same result by assuming that T is compact and X is an arcwise connected Hausdorff space. In this note, under the same assumption as Wang's,we prove that T has countably many fixed points. In fact, we prove the follow: ing: THEOREM: Let (X, T, π) be a transformation group where X is an arcwise connected Hausdroff space. Let A be a closed T-invariant set B, $B \cdot A = \phi$, by a point. If there is such a closed set B, then T has at least two distinct fixed points, one of them contained in A. If, furthermore, every orbit, under T, is closed, then T has countably many fixed points.

W. R. Garrett, "Polarization and Exchange Effects in Slow Electron Scattering From Lithium and Sodium," to appear in Physical Review.

Abstract: Total elastic scattering cross sections have been calculated for low energy electrons incident on lithium and sodium. The effects of target distortion by the electric field of the incident particle and electron exchange between incident and bound electrons have been included through the "adiabatic exchange" approximation. In this method, the effect of the distortion induced in the target atom is computed through a polarization potential which is obtained by the method of polarized orbitals. The phase shifts and the total elastic scattering cross sections are obtained through the solution of a set of integrodifferential equations. The calculated polarization potential agrees asymptotically with experimental determinations of the dipole polarizability of Li and Na, and the total elastic scattering cross sections agree well with recent measurements over the entire experimental range. Results for both alkalis exhibit a small resonance at the experimental peak around 1 volt and a second peak at lower energies outside the present experimental range.

A. A. Hayday, "On Heat Transfer from Isothermal and Non-Isothermal Spinning Bodies of Revolution," presented at the Winter Annual Meeting of the American Society of Mechanical Engineers, New York, Nov. 29-Dec. 4, 1964, and to appear in Journal of Heat Transfer.

Abstract: The class of similar flows engendered by bodies of revolution rotating uniformly about axes of symmetry in an otherwise undisturbed fluid is studied. Local heat transfer by forced convection is determined theoretically for laminar flows under both isothermal and nonisothermal surface conditions. It is shown that the known solutions for rotating disks and cones are special cases which fall within the scope of this analysis. The flows are in general characterized by continuously thinning boundary layers formed along the body surface. Criteria which determine such boundary-layer behavior are related to the similarity transformations and also to the rates of change of cross sectional areas of the bodies in question. The thinning boundary layers imply higher local friction and moment coefficients than those found for comparable cones. The same is true for local Nusselt numbers. Estimates of the region of validity of the results are given, and the results are tabulated for several Prandtl numbers. The role of free convection is discussed briefly.

A. A. Hayday, "Similar Flows About Axisymmetric Bodies Rotating in a Fluid At Rest," to appear in Applied Scientific Research, Section A, Vol. 14 (Physics & Mathematics).

Abstract: The class of similar flows engendered by members of a corresponding class of bodies of revolution rotating about axes of symmetry in an otherwise undisturbed fluid is discussed. Several examples of such flows are considered in detail under the assumptions that the physical properties of the fluid are constant and that dissipation and curvature effects are negligible. The well known flows associated with rotating disks and right circular cones are shown to be two special cases.

C. D. Johnson and W. M. Wonham, "On a Problem of Letov in Optimal Control," ASME Transactions, Journal of Basic Engineering, March, 1965.

Abstract: In a series of papers, A. M. Letov discussed an optimal regulator problem for a linear plant with bounded control variable and quadratic performance index. This problem was also discussed by Chang. Krasovskii and Letov observed later that the solution

proposed in these papers may be correct only for special choices of the initial value of the state vector. In the present note, further aspects of the solution in the general case are described and three examples are given. The possible existence of a regime of unsaturated-nonlinear optimal control is demonstrated. The presence of this regime in the optimal control law was apparently overlooked in the papers mentioned above.

F. H. Mitchell, Jr., "Microwave Propagation in Inhomogeneous Plasma," paper to be presented at First IEEE Annual Communications Convention in Boulder, Colorado, June 7-9, 1965.

Abstract: Microwave propagation in plasma sheaths is discussed in detail and several methods for studying the problem are described. Both homogeneous and inhomogeneous plasmas are considered and representative models are analyzed. The polarizability and conductivity of a plasma are examined and the electromagnetic fields computed for several cases of interest.

F. H. Mitchell, Jr., "Radiation From Magnetic Line Source Arrays Into Inhomogeneous Plasma," Transactions of IEEE Group on Antennas and Propagation (Communication), to appear September, 1965.

Abstract: This paper considers the problem of radiation from an array of constant-phase magnetic line sources on a conducting plane into an inhomogeneous plasma. The radiated power is found as a function of the thickness of the plasma sheath.

F. H. Mitchell, Jr. and F. J. Tischer, "Radiation Through Plasma Adjoining a Conducting Surface," Transactions of IEEE Group on Antennas and Propagation (Communication) to appear May, 1965.

Abstract: A method for the study of electromagnetic wave propagation on inhomogeneous plasma media is described, where the solution is in the form of an integral recursion relation. The technique is most useful for weakly ionized plasmas. An appropriate example is worked out and the results discussed briefly.

H. Y. Yee, "Natural Resonant Frequencies of Microwave Dielectric Resonators," IEEE Transactions on Microwave Theory and Techniques, March, 1965.

Abstract: An approximate method is developed for determining the natural resonant frequencies of microwave dielectric resonators. This method is based on the approximate open-circuit boundary conditions at surfaces between air and the dielectric with high permittivity. Experimental results show good agreement with the theoretical calculations.

H. Y. Yee and F. J. Tischer, "On the Wave Propagation in Nonuniform Media," to appear in Proceedings of IEEE.

Abstract: The problem of wave propagation in nonuniform media is considered by a new approximate method. This method is applicable to permittivities of dielectric media with variation in only one spatial coordinate.

C. Papers submitted for publication during September 1, 1964 to February 28, 1965:

Hsin Chu, "Another Note on Transformation Groups with A Fixed Point End," submitted to Portugal Mathematics Journal.

Abstract: Professor A. D. Wallace proved the following results: "Let (X, T, π) be a transformation group where X is a Peano continuum with a fixed end point under T and T = the discrete, additive group of all integers. Then T has another fixed point." Professor H. C. Wang proved that the same statement is true if T is a compact group. Chu proved that it is also true for a locally compact group G which contains a closed subgroup $C = R^n \cdot Z^m$, where n is non-negative integer and m = 0, 1, R = that additive group of all real numbers with the usual topology, Z = the additive group of all integers with the discrete topology, and $R^n \cdot Z^m$ is a direct sum of R^n and Z^m, such that G/C is compact. In this note, we establish that the same statement is true for a locally compact group T which contains a compact normal subgroup K such that $T/K = R^n \cdot Z^m$, where $R^n \cdot Z^m$ is defined as above. We also prove that the statement is true for an abelian group, generated by a compact neighborhood of the identity, with a certain condition.

Hsin Chu, "Compactification and Duality of Topological Groups," submitted to Transactions, The American Mathematical Society.

Abstract: In abstract harmonic analysis, there is a compact group attached to a group in the sense of Weil on one hand. In topological groups there are the Pontrjagin duality for locally compact abelian groups and the Tannaka duality for compact groups on the other hand. In this paper, we use a unified formulation to investigate these two theories together.

Hsin Chu, "Some Inheritance Theorems in Topological Dynamics," submitted to The London Mathematics Journal.

Abstract: In Topological Dynamics, the inheritance theory plays an important role. We present here some inheritance theorems concerning star-closed partitions, as well as, locally weakly almost periodicity, and weakly almost periodicity. These results are both interesting and apparently new.

Hsin Chu and P. A. Lucas, "An Elementary Problem on Numbers," submitted to the Pentagon Journal of Mathematics.

Abstract: In this note we consider the following problem: "Let T_o be an unknown number of objects such that no object can be divided into a fractional part. If p/r parts of T_o plus s/r of one object are removed from T_o, where $0 < s < r$ and $0 < p < r$, the remainder, T_1, has no fraction. If the process is continued n times, so that p/r parts of T_k, plus s/r of one object are removed from T_k, leaving a remainder, T_{k+1} $(k=0, 1, 2, \ldots, n-1)$, which has no fractional parts, the last remainder, T_n, will be zero. Can one determine how many objects there were in the beginning?" The answer is quite elegant and simple, namely:

(a) If sr^i is not divisible by $(r-p)^{i+1}$ for all $i=0,1,2, \ldots, n-1$, the problem has no solution.

(b) If sr^i is divisible by $(r-p)^{i+1}$ for all $i=0,1, \ldots, n-1$, then

$$T_{(o,n)} = \frac{s}{r-p}\left[\frac{\left(\frac{r}{r-p}\right)^n - 1}{\frac{r}{r-p} - 1}\right].$$

A. A. Hayday, "On Axioms for Heterogeneous Continua," submitted for publication.

Abstract: (not available)

A. A. Hayday, "On Balance Equations for Heterogeneous Continua," submitted for publication.

Abstract: The paper presents, from the viewpoint of classical continuum physics, a rigorous derivation of the general balance equations for heterogeneous continua-substances consisting of many distinct, possibly interacting, constituents. The treament is a direct generalization of the well known theory for a simple (one-substance) continuum and covers multicomponent media in solid, liquid and gaseous forms. The work rests on axioms in integral form stated for the constituents of the heterogeneous continuum, using well defined material volumes for the medium as a whole. An explicit hypothesis is introduced asserting how a constituent of a heterogeneous medium is influenced by the totality of the others. This hypothesis allows for general interactions among the constituents and, in principle, covers the special results for liquid helium mixtures given by Prigogine and Mazur. All properties

of the heterogeneous continuum as a whole are consistently deduced from the corresponding properties of the constituents. In particular, the overall integral balance equations are derived by summing over all components the corresponding balance equations for the constituents. The differential balance equations for the heterogeneous continuum are consequences of the corresponding integral balance equations and a requirement that specifies the mathematical form of the resultant equations. Herein, this requirement is a general structural hypothesis that, in certain special cases of gaseous mixtures, agrees with known results of kinetic theory. While our development differs from that of Truesdell, it may be considered as an integral equivalent to his and a completion of the program he started.

C. D. Johnson, "A Note on Normal Forms for Nonlinear Control Systems," submitted for publication.

Abstract: Several different "normal forms" have been used to study nonlinear control systems having one isolated nonlinearity. This note proposes a new normal form which offers certain advantages over those currently in use.

J. H. Kallweit, "The Relationship Between the Viscosity and the DC Conductivity in PVC," submitted to Journal of Polymer Science.

Abstract: In general, it has been said that the dc-conductivity σ is proportional to the inverse of the viscosity η. But the relation $\sigma \cdot \eta = \text{const}$ has not been proven in the case of the system PVC/DOP. The experimental results can be described by $\sigma \cdot \eta^{\frac{m}{m-1}} = \text{const}$ if the plasticizer content is not too high. The ion mobility seems to depend on a local effective viscosity, which differs from that viscosity which is derived from retardation experiments.

H. Y. Yee and N. F. Audeh, "Wave Propagation in Groove Guides," submitted to IEEE Transactions on Microwave Theory and Techniques.

Abstract: A groove guide consists of two parallel conducting plates with two grooves cut at the center in the longitudinal direction. The air filled deformed guide can be transformed into a parallel-plane guide filled with a nonuniform anisotropic dielectric. The posed boundary value problem was solved by approximation techniques; the results were experimentally verified. The groove guide has the advantages of transporting most of the energy in the groove region, having a very low attenuation constant and, under certain conditions, propagating the dominant modes only.

D. The Interim and Final Reports on Contracts and Specific Grants Issued by Staff Members

1. H. Y. Yee, Final Technical Report for period February 1, 1964 - January 31, 1965, "Approximate Methods for the Computation of Wave Propagation in Nonuniform Media," NsG-608.

2. R. A. Mann, Quarterly Progress Reports for periods May 28, 1964-August 27, 1964, August 28, 1964-November 27, 1964, November 28, 1964-February 28, 1965, "Interactions of Slow Electrons with Light Gas Atoms," Contract NAS8-11249.

3. Vincent M. McCarty, Quarterly Progress Report for period September 22, 1964 - December 22, 1964, "Investigation of Earth Tremors During Large Rocket Firings," Contract NAS8-11202.

4. C. D. Johnson, Quarterly Progress Reports for periods July 1, 1964-October 1, 1964 and October 1, 1964-January 1, 1965, "Basic Research in the Mathematical Theory of Automatic Control," Contract DA-01-009-AMC-165(Z).

5. R. A. Mann, Quarterly Progress Reports for periods August 15, 1964-November 15, 1964 and December 15, 1964-March 15, 1965, "Investigation of Surface Ionization on Metallic Surfaces," Contract NAS8-2585.

6. Hsin Chu, Quarterly Progress Reports for periods September 1, 1964-December 1, 1964 and December 1, 1964-March 1, 1965, "Topological Dynamics," Contract NAS8-1646.

7. F. J. Tischer, Interim Report No. 4, "Parameter Optimization," Contract NAS8-5411.

8. Jurgen Thoenes and Rudolf Hermann, Quarterly Progress Reports for the periods June 30, 1964-September 30, 1964 and October 1, 1964-December 31, 1964, "Inviscid High Temperature Hypersonic Flow of Air Past Pointed Bodies of Revolution," Contract DA-01-009-AMC-166(Z).

APPENDIX III

Present and Planned Research Programs of the Research Institute

A. Hypersonic High-Temperature Gas Flow - Dr. Rudolf Hermann, Professor of Physics and of Aerospace Engineering, and Director, Research Institute, Dr. R. L. Causey, Associate Professor of Mathematics and Head of the Computer Science Laboratory, Mr. K. O. Thompson, Research Associate, and Mr. Jurgen Thoenes, Senior Research Assistant, will continue the studies of the flow fields around blunt bodies in non-equilibrium hypersonic flow. Dr. J. J. Brainerd will join the group as Associate Professor of Aerospace Engineering in July, 1965. In the past year calculations were made for the subsonic portion of a hemispherical body using a simplified air model valid in the region of oxygen dissociation. The equations of motion were particularized for the stagnation stream line, which do not require a priori assumption of equilibrium at the stagnation region. They show the flow for most cases is not in equilibrium.

During the coming year, it is planned to extend the calculations to include several species in non-equilibrium flow. In the subsonic portion,the method of integral relations as proposed by Dorodnitsyn-Belotserkovskii will be used; in the supersonic region,the DB method as well as some finite difference scheme equivalent to a method of characteristics solution will be used. The two methods will be compared for accuracy and speed of computation. Studies will be made to extend the DB method to the second approximation.

The effects of vehicle (or model) size will be investigated for non-equilibrium flow. The necessary size to approach equilibrium for a variety of free stream conditions will be determined. Both blunt and pointed bodies will be studied.

The hypersonic non-equilibrium boundary layer on a hemisphere cone body in non-equilibrium hypersonic flow will be investigated by Dr. Brainerd.

The other work described will be done by Dr. Causey for the numerical analysis and computer aspects and by Dr. Hermann, Mr. Thoenes, and Mr. Thompson for the gas kinetic and aerodynamic aspects.

B. Detection and Information Processing with Memory Type Decision Circuit - Dr. R. J. Polge, Associate Professor of Electrical Engineering, and Dr. J. C. Chang, Research Associate, are working in the area of communications. Presently, they are conducting research in the detection of coded pulse-type signals in the presence of noise or jamming signals. Instead of using the conventional constant threshold

devices, a new scheme with adaptive threshold level is being investigated in order to reduce the error probability of detection. It can be anticipated that the scheme can be applied to the reception of command and guidance signals, detection of coded radar signals, and other applications, in particular in transmission where high data rates are important.

The error probability for constant threshold and adaptive threshold have been compared for white noise of normal distribution, no gating, RC filter and white noise of normal distribution, gating, RC filter.

The parameters of interest are the power spectrum of the noise, the amplitude of the pulse before filtering, the width of the pulse and the time constant of the filter.

In the minimization of the probability of error, two types of constraint are used: either limited amplitude and variable width or limited energy of the pulse.

Although a continuous variation of the threshold gives the best results, a discrete variation is also investigated because of its simplicity. In the adaptive scheme, the noise must be predicted and the threshold varied accordingly. If T is the interval between two signals, the prediction of the noise at time t + T, knowing the noise at time t, is based on the value of the autocorrelation function R (T). Besides filtering, the RC network increases R (T) and therefore increases the accuracy of the prediction. The RC filter changes also the shape and the width of the pulses. The amplitude increases in a sequence of overlapping pulses because the initial charge of the condenser is increasing every time.

Analytically the average probability of error for the optimum choice of the adaptive threshold has been found and compared with the case of constant threshold. The effect of gating is an increase of the signal to noise ratio by a factor $\frac{1}{1-e^{-20/RC}}$.

The results will be checked experimentally, the frequencies being scaled down to make the study easier.

Because of the complexity of the problem, only the special case of white noise with RC filter and adaptive scheme with short memory (mainly Markov type) has been considered.

The theoretical analysis will be expanded to include different types of noise distribution. Since, during the reception, the structure of the noise can change or even be unknown (as is the case in outer space communications), the adaptive scheme should be able to perform satisfactorily in either case. The RC filter is not the best choice, other types of filters should also be investigated.

The noise used for prediction has been sampled at the end of the pulse. If instead, a variable delay technique is used, the autocorrelation coefficient could be increased and the probability of error reduced.

Experimentally a more realistic scheme at high frequency should be tested.

C. Wave Propagation in Nonuniform Anisotropic Media - Mr. H. Y. Yee, Research Associate, and Dr. N. F. Audeh, Associate Professor of Electrical Engineering, plan to continue the investigations of wave propagation through plasma as encountered during the re-entry phase of a space vehicle. This field has been the subject of a program at the Research Institute during the past two years.

From the macroscopic point of view, the effect of the interaction between free electrons and electromagnetic waves in a region of plasma in the absence of DC magnetic fields can be represented as a nonuniform isotropic dielectric. In the presence of DC magnetic fields, however, the plasma behaves as a nonuniform anisotropic medium.

Yee has used approximate methods for computation of propagation of a plane wave through a nonuniform isotropic medium.[1] He also investigated the scattering problem of waves by a dielectric cylinder of similar material, and by a conducting cylinder immersed the same medium. The methods of collocation and least squares have been used. Such methods have the advantage of liberalizing the stringent

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[1] Yee, H. Y., "Approximate Methods for the Computation of Wave Propagation in Nonuniform Media," Interim Report No. 1, Grant No. NsG 608, Sept. 1, 1964, University of Alabama Research Institute, Huntsville, Alabama.

condition imposed by other authors[1,2,3] on the behavior of the material. All of the above problems are limited to one spatial variation; at present there is no discussion available for the nonuniform anisotropic media. The model of only one spatial variation is not adequate to represent the re-entering vehicle in many cases. The nonuniform anisotropic model is another problem of considerable interest in space communication, since the presence of static magnetic field may eliminate the re-entry blackout as pointed out by Hodara[4]. The contribution of a moving nonuniform medium to the Doppler effect is also an important aspect in space communication.

Theoretical investigations are contemplated to solve some of the following problems:

(1) Wave propagation in isotropic nonuniform media where the variation involves two or three spatial coordinates.

(2) Wave propagation in anisotropic nonuniform media.

(3) Scattering of a plane wave by a moving medium.

The wave equations for propagation in nonuniform media are quite complicated. However, there are many approximation techniques and numerical methods available for solving the wave equations. It is expected that some simple models would yield instructive results by applying one or more methods.

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1 Richmond, J., "Transmission Through Inhomogeneous Plane Layers," IRE Trans. on Antenna and Propagation, AP-10, 300 (May, 1962).

2 Albini, F. A., and Nagelberg, E. R., "Scattering of a Plane Wave by an Infinite Inhomogeneous Dielectric Cylinder - An Application of the Born Approximation," J. Appl. Phys., 33, 1606 (May, 1962).

3 Rusch, W., "Radiation From an Axially Slotted Cylinder With a Radially Inhomogenerous Plasma Coating," Canadian Journal of Physics, 26 (January, 1964).

4 Hodara, H., "The Use of Magnetic Fields in the Elimination of the Re-Entry Radio Blackout," IRE Trans. on Antenna and Propagation, AP-49, 1825 (December, 1961).

D. Grove Guide for Millimeter Wave Transmission - Dr. N. F. Audeh, Associate Professor of Electrical Engineering, and Mr. H. Y. Yee, Research Associate, have been conducting research in groove guide in the X-band. They plan to continue this project and extend it to higher frequencies.

A parallel plane waveguide with a dielectric slab in the middle extending in the direction of propagation is called H-guide, because the cross sectional view has the shape of letter H. Tischer[1] has shown that the electromagnetic energy is transported in the vicinity of the dielectric slab. Only a portion of the energy is transported outside the slab.

Tischer[2] also showed that if two longitudinal grooves are cut in the walls of the parallel-plane guide, the grooved-guide can be transformed by conformal mapping into an H-guide. The energy is concentrated in the vicinity of the groove. The electromagnetic energy decays exponentially in the transverse direction, away from the groove region. The decay is large--in order of 50 nepers per meter. When a TE mode is excited, the plates of the guide need not to be infinitely wide, because of the large decay factor. In addition there is no need for terminating the line at the sides to simulate infinity.

A parallel-plane guide has been shown to have a decreasing attenuation with increasing frequency. Mr. Yee and Dr. Audeh have shown that the attenuation of the groove guide is less than that of the parallel-plane guide, as in the following equation.

$$\alpha_g = \alpha_p \left(\frac{f_g}{f_p}\right)^4 \left[\frac{1 - \left(\frac{f_p}{f}\right)^2}{1 - \left(\frac{f_g}{f}\right)^2}\right]^{1/2}$$

where α_g = groove-guide attenuation constant

α_p = parallel-plane guide attenuation constant

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[1] Tischer, F. J., "The H-guide, a Waveguide for Microwaves," IRE Convention Record, pt. 5, 44-51 (1956).

[2] Tischer, F. J., "The Groove-guide, a Low Loss Waveguide for Millimeter Waves," IEEE Transactions on Microwave Theory & Techniques, Mtt-11, No. 5, 291-296 (September, 1963).

f_g = cut-off frequency of the groove guide

f_g = cut-off frequency of the parallel-plane guide

and $f_g < f_p$.

This relationship shows that the groove guide may be useful for millimeter wave transmission, a problem which has not yet been solved with reasonable practicality.

A groove guide has been built for X-band transmission. The field distribution has experimentally been detected. The wave was launched by a horn which unfortunately introduces fringing off its walls. Presently, the attenuation constant is being determined by using a groove guide cavity. By measuring the Q-factor, the attenuation constant can be determined.

It will be undertaken in the future:

(1) To launch waves in the guide so that fringing is eliminated. One method which will be considered is the use of a dielectric lens.[1]

(2) To increase the frequency to K-band. Ultimately, if successful, the frequency will be increased to the millimeter band.

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[1] Audeh, N. F., and Yee, H. Y., "On Dielectric Lenses." To appear in the correspondence section of IEEE Proceedings.

E. Research in Dielectrics - Dr. J. C. Dowdle, Associate Professor of Electrical Engineering, and Dr. J. H. Kallweit, Senior Research Associate, have prepared a preliminary draft of a paper entitled "A Note Concerning K. W. Wagner's After-Effect Function." This work represents the initial investigation in the field of powdered dielectrics at the University of Alabama Research Institute.

Dowdle plans a continuation of his work to ascertain the dielectric constant of solid materials without the requirement of a specific geometry for the solids in question. Instead of subjecting the materials to machining processes, the materials would be ground or pulverized into powderlike particles. The method under consideration lends itself quite readily to materials which inherently appear in granular form. The work could be extended to the investigation of powdered semiconductors, which may be used as photo-resistors or in photocells for the detection of infrared radiation.

Dowdle[1] began a study of a number of dielectric mixture relations, including the well-known relations of Bruggeman, Wiener and Lichteneker, in order to determine the dielectric constant of one of the constituents of a mixture when the dielectric constant of the discontinuous phase was unknown but that of the continuous phase was known. In each of these relations the dielectric constant of the mixture, $\mathcal{E}_m$, is given for a two-phase mixture in terms of the dielectric constant of the continuous phase, $\mathcal{E}_c$, the dielectric constant of the discontinuous phase, $\mathcal{E}_d$, and the volume percentage of the discontinuous phase, V_d.

Pearce[2, 3] assembled his empirical relation for porphyritic mixtures,

$$\frac{\mathcal{E}_m - \mathcal{E}_c}{\mathcal{E}_d - \mathcal{E}_c} = \frac{(1-h)\ Vd}{(1-h\ Vd)}$$

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1 Dowdle, Joseph C. "Determination of the Dielectric Constant of Solid Dielectrics Through an Application of Pearce's Equation," University Microfilms, Ann Arbor, Michigan (1962).

2 Pearce, C. A. R., "The Electrical Conductivity and Permittivity of Mixtures, With Special Reference to Emulsions of Water in Fuel Oil," Brit. J. Appl. Phys. 6, 113-120 (1955).

3 Pearce, C. A. R., "The Permittivity of Two-phase Mixtures," Brit. J. Appl. Phys. 6, 385-361 (1955).

where h is defined only with respect to test results and had no derivation from shape factors.

In the preparation of a given mixture it is necessary to know the corresponding value of h before calculating the dielectric constant of the mixture from its constituents. This requirement of a knowledge of h limits the use of Pearce's equation in the classical sense of being able to determine mixture characteristics from the constituents. However, as Dawdle has shown, the value of h can be determined statistically from a group of data on several mixtures having different concentrations of the same constituents, even when the dielectric constant of one of the constituents is unknown. It is thus through establishing the proper value of h for Peacre's equation that a determination was made of the dielectric constant of powdered dielectric materials. However, this investigation was restricted to frequencies of less than 100 kilocycles and to a ratio of $\mathcal{E}_d/\mathcal{E}_c$ of less than six.

Maximum advantage in the current studies would be derived for the higher permittivity materials at frequencies in the gigacycle range. However, additional investigation is needed in the frequency ranges below 1.0 gigacycle. For the lower permittivity materials the dielectric powders may be measured somewhat conventionally as by Mukharev, Perelman, and Rogova [1]. This scheme, however, has the disadvantage that the wavelength in the guide section containing the mixture must be large with respect to the cell size. It is intended that transmission methods be used on the higher permittivity materials as discussed by von Hippel [2, 3].

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1 Mukharev, L. A., Perelman, A. M., and Rogova, N. A., "Determination of the Permittivity of Materials at High Temperatures in the 3-CM Range of Radio Waves." Pribory i Tekhn. Eksper 5, 138-141 (Sept. – Oct., 1961).

2 Hippel, A. von (ed.) Dielectric Materials and Applications. New York: John Wiley and Sons, Inc., (1954).

3 Hippel, A. von (ed.) Dielectrics and Waves. New York: John Wiley and Sons, Inc., (1954). (1954)

It is proposed to do the following:

(1) A thorough investigation will be made on all published two-phase dielectric mixture relations. (Computer programs will be prepared to display these comparisons.)

(2) A method will be developed to obtain dielectric constant-versus-concentration data in the frequency range from 1.0 to 3.0 megacycles.

(3) A method will be developed to obtain dielectric constant-versus-concentration data in the frequency range from 50 to 500 megacycles.

(4) A method will be developed to obtain dielectric constant-versus-concentration data in the frequency range from 0.9 to 4.3 gigacycles.

(5) Pearce's relation will be evaluated using the data of (2), (3) and (4), as a means for determining the dielectric constant of solid materials in the frequency range from 1.0 megacylce to 4.3 gigacycles.

(6) As time permits other mixture relations will be investigated using the data of (2), (3), and (4).

Dr. Kallweit will continue work performed before joining the Research Institute concerning the relation between viscosity and conductivity. Since joining the Research Institute his analysis of former experiments has shown that it should be possible to use viscosity measurements to derive the mobility and concentration of ions in dielectrics when the measurement of the Hall-Voltage or the transference number is not possible due to currents of insufficient magnitude. The evaluation of the experimental results has shown that the viscosity values which were obtained by retardation experiments ("macroviscosity") cannot be used in connection with the specific conductivity of the sample. But they give the possibility for the definition of a "microviscosity", which describes the friction force on ions in the field of neighboring molecules or molecular groups. Experiments are planned to check this new hypothesis. The derived values for the mobility, diffusion coefficient, and the mean free path of the ions are in fair agreement with values from other authors.

F. Research on Transmission, Reflection and Diffraction of Coherent Light - Dr. R. A. Mann, Associate Professor of Physics, and Mr. W. L. Gamble, Research Assistant, plan to continue work on studies related to the intrinsic divergence associated with laser beams. These studies are concerned with the properties of laser rods that cause divergence in excess of that associated with diffraction from a finite aperture. As a part of this study some consideration will be given to the problem of treating scattering of photons from excited ions when the photon occupation number is very large.

An experimental program is being considered to study the scattering of light by phonon (Brillouin scattering). This program would use lasers in connection with appropriate detectors to study various properties of lattice dynamics.

G. Research in Optics - Dr. J. H. Kallweit, Senior Research Associate, has a major interest in experimental physics. Recent work has been directed toward the development of the concept of an optical instrument which allows the measurement of the size of objects at a great distance when the distance of the observer to the object is known. The concept is based on interferometric principles. The most significant difference from other types of interferometers is that the fringe system is not considered but rather the instrumental condition for the formation of interference fringes. This method will not give the theoretical high accuracy usually associated with interferometers, but it allows a simple and quick determination and the possibility to observe and compare different neighboring objects at the same time with good accuracy. Experiments have shown that the concept is feasible and that the method can be improved.

A differential interferometer has been installed. It will be used for experimental work in the field of boundary layers and heat transfer. Experiments are in preparation to check theoretical calculations of Dr. A. Hayday, University of Alabama Research Institute, published in the following:

1. "On Heat Transfer From Isothermal and Nonisothermal Spinning Bodies of Revolution." Presented at the 1964 Winter Annual Meeting of the ASME, to appear in the Journal of Heat Transfer.
2. "Similar Flows About Axisymmetric Bodies Rotating in a Fluid at Rest." To appear in Applied Scientific Research, Section A.

Experimental work in the field of light reflection on various types of surfaces will be undertaken. It is planned to investigate the light distribution after reflectance with highest possible accuracy. Different light sources, including coherent light of lasers, will be considered. Studies are considered with respect to the possibility of making reflectance measurements in the far infrared to 700 μ.

H. Experiments in Chemical Physics - Dr. W. F. Arendale, Professor of Chemistry and an Assistant Director of the Research Institute, plans studies on the behavior of molecules in highly excited states, particularly dissociation and bond formation. Work with materials in the excited states as may be obtained under conditions generated by plasma and arc equipment has been considered. Experimental work in this area is delayed until installation of equipment is completed.

Molecules may be placed in excited states by absorption of electromagnetic radiation. Absorption of energy in the near infrared region of the spectrum produces vibrational excitation of molecular bonds. Absorption of ultraviolet radiation produces molecules in excited electronic states. Absorption of energy can be equivalent to raising the temperature. The use of the laser to generate coherent and monochromatic radiation adds a tremendous new dimension to studies in chemical physics. Special attention will be given to those experimental conditions using laser equipment that result in molecular fragmentation. Attempts will be made to stimulate selected chemical activity by choice of frequency and intensity of the light beam. Localized high temperatures will be studied as possible means of initiating selected chemical reactions. It is hoped that new materials of construction applicable to space systems can be generated by initiating polymerization reaction in this manner. Since low pressures are encountered in space applications, it may prove advantageous to study certain of the energy absorption processes at low pressures.

I. Theoretical Atomic Physics - Dr. Robert A. Mann, Associate Professor of Physics, and Dr. W. R. Garrett, Assistant Professor of Physics, are working in the area of atomic physics. The results are of interest to people who are involved in investigations in upper atmosphere physics, planetary atmosphere studies, studies of radiation belts, the general area of plasma physics, wave propagation through plasmas, and certain laser problems. The work can be divided into the following three areas:

1. Low Energy Electron Scattering, Elastic and Inelastic

A considerable amount of work has been done in calculating low energy elastic scattering cross sections for electrons on the alkali metal vapors. The major effort in these investigations has been the development, through perturbation theory, of a suitable interaction potential to describe the scattering process at low energy. This work has led to very good results in agreement with available experimental data. Further investigations of elastic scattering will include extension to other atomic systems of the methods developed at present, and further investigation of the effects of exchange in the low energy region in particular, through the adiabatic exchange approximation.

The satisfactory treatment of the polarization of the atomic system by an incident charged particle in the elastic scattering process gives some hope that the final state interaction in inelastic scattering processes might be handled through an analogous approach. An effort will be made to describe the inelastic scattering process with the inclusion of the final state interactions through a polarization potential similar to that used successfully in the elastic scattering interaction.

2. Ion-Photon Processes

a) Photo-ionization and Detachment

The method of calculating a suitable interaction potential for a charged particle and an atomic system has applications in areas other than that of low energy electron scattering. It is equally important that the proper final state interaction be used to describe low energy photo-ionization and detachment processes. The perturbation method which has successfully described the scattering

interaction can be used to calculate the potential for the detached electron in the interactions

$$A + h\nu \rightarrow A^+ + e^- \qquad 1)$$

$$A^- + h\nu \rightarrow A + e^- \qquad 2)$$

That is, photo-ionization and photo-detachment, particularly in the infrared and visible regions. Failure to account for the distortion of the final state system in calculations of photo-detachment cross sections for negative ions such as O^-, N^-, Na^-, etc., are in error by more than an order of magnitude.

Earlier calculations of processes 1 and 2 above have included polarization in the final state largely through semi-empirical methods adjusted to fit experimental data. Use will be made of the perturbation method of calculating the final state interactions in either the dipole length or dipole acceleration formulation.

b) Two Body Recombination Cross Sections.

The inverse of the above process, i.e., electron attachment or recombination can be obtained in similar calculations to those of processes 1 and 2. The important differences here are recombination into excited states where polarization effects are again very important.

3. Atomic Polarizabilities in Ground and Excited States

A calculation which comes almost as a by-product of the above consideration is the dipole polarization of an atomic system in the ground state or excited state, thus being obtainable from the asymptotic value of the polarization potential as discussed above. This information is useful in various applications. In particular, the average dipole polarizability of a statistical distribution of highly excited but weakly ionized gas atoms will be investigated with the resultant dielectric properties of the gas determined for the purpose of determining the effect of such a dipole gas on wave propagation through the medium.

J. Experimental and Theoretical Studies Related to Surface Physics - Dr. R. A. Mann, Associate Professor of Physics, is the principal investigator for studies of the atomic interactions at surfaces (predominantly metals) under controlled conditions such that clean surfaces are studied. At the present an experimental program is under way to study adsorption, desorption and surface ionization as functions of temperature, electron bombardment, and other variables. The techniques of field emission microscopy are being used. A special technique involving the use of chopped molecular beam apparatus in combination with a field emission tube is in the process of being developed so that studies of adsorption and desorption at high substrate temperatures may be carried out. Field emission ion microscopy studies have also been initiated so that the atomic structure of the substrate may be determined.

A theoretical program is being carried out in connection with the experimental work. The purpose of the theoretical work is to provide an understanding of the experimental results and to suggest further areas in which experimental studies are required. The effects of the potentials occurring at a surface are being considered in relation to the observed surface ionization effects and the temperature dependence. Certain studies related to the migration of ions on metallic surfaces are also expected to be undertaken.

K. Electron Shielding - Dr. C. P. Bhalla, Assistant Professor of Physics, has work in progress and plans additional work in electron shielding and nuclear physics. In recent years, shielding of sensitive equipment (e.g. in a satellite) against electron bombardment has become increasingly important. In the usual theoretical formulations, one uses approximate electron wave functions to calculate the effectiveness of a particular shielding material; introducing errors which may not be negligible.

Work in the calculations of better electron functions has been initiated in the last year by Dr. Bhalla. In brief, the finite nuclear size of a nucleus and the atomic screening effects is considered. Preliminary calculations indicate that such a program can be pursued profitably by numerical integration of the electron radial equations using a realistic potential.

The electron functions and phase-shifts for the appropriate values of the total angular momentum will be computed. These calculations will be performed by numerical integration of the Dirac equation.

The appropriate values of these radial wave-functions will be calculated for the potential specified by the following equation ($\hbar = m = c = 1$)

$$V(r) = \frac{-\alpha (Z)}{2\rho} \left[3-\left(\frac{r}{\rho}\right)^2\right] \qquad \text{for } r \leq \rho$$

where ρ is the nuclear radius in units of $\hbar/mc$ and Z is the atomic number. The fine structure constant, α, is 1/137.037. R_A will denote the atomic radius.

$$V(r) = V \text{ (Hartree-Fock)} \qquad \text{for } \rho \leq r \leq R_A$$

$$V(r) = 0 \qquad \text{for } r \geq R_A.$$

A computer program will be developed, and the results available in the literature on Hartree-Fock potential will be used.

The Thomas-Fermi screening potential will also be considered. In this case, the calculations will be performed by employing the following potential for the electron:

$$V(r) = -\frac{\alpha (Z)}{2}\left[3 - \left(\frac{r}{\rho}\right)^2\right] \qquad \text{for } r \leq \rho$$

$$V(r) \simeq -\frac{\alpha Z}{r}\phi(\mathcal{H}) + \frac{\alpha^2}{2\pi^2} - D(r, P_i) \text{ for } \rho \leq r \leq R_A$$

where R_A = atomic radius and $0(\mathcal{H})$ is to be calculated from

$$\frac{d^2\phi}{dx^2} = x\left(d + \phi^{1/2}/x^{1/2}\right)^3$$

$$\text{with } d \equiv \left(\frac{3}{32\pi^2}\right)^{1/3} Z^{-2/3}$$

The screening factor $\phi(\mathcal{H})$ will be calculated first by numerical integration of the last equation. This will involve several iterations so as to obtain a reasonable atomic radius, where ϕ is equal to zero.

The phase-shifts will be calculated in both cases by comparing the calculated values with the expected asymptotic behavior of the radial functions, f_{ℓ} and g_{ℓ}.

It is expected that calculations, based on this work, would provide a realistic function for the electron shielding calculations. At the present time, the Runge-Kutta method is being investigated for numerical integration of the relevant equation.

L. Control Theory - Dr. C. D. Johnson, Associate Professor of Electrical Engineering, has a major interest in the mathematical theory of automatic control. He will continue to study game theoretic problems in optimal control with particular emphasis on the singular solutions which arise in such problems. In addition, a study will be made of dynamic optimization problems with non-Markovian payoff. Mr. Rolf Duerr, Research Assistant working with Dr. Johnson, will investigate the feasibility of "machine solutions" for domains of asymptotic stability using a high-speed, hybrid, analog computer.

Mr. C. F. Chen joined the Research Institute in November, 1964, as a Research Associate. In his studies of Liapunov's stability theorems, a significant result has been achieved which is to construct Liapunov's function by the Routh's Algorithm. The report was accepted by IEEE Proceedings and will be published in the near future.

Mr. Chen also plans to extend the Routh Algorithm to find the Liapunov's functions on a feedback system with a single nonlinearity by (1) Using the Puri and Wygandt method to find the transformation matrices by which an arbitrary system can be converted into a Schwarz' form; (2) Applying Zubov's digital computer techniques to evaluate the domain of asymptotical stability compared with the result possibly obtained from the first step.

M. Mathematics - Dr. R. L. Causey, Associate Professor of Mathematics, is presently concerned with research in mathematical analysis and computer science (including numerical analysis). He is charged with the coordination and development of the University's computing activities utilizing the UNIVAC 1107 center located at the Research Institute.

Research activities anticipated for the third grant year include study of (1) numerical methods for solving nonlinear ordinary and partial differential equations, (2) approximation problems in matrix spaces, (3) computer methods for solving problems

involving very large matrices, (4) optimum mechanization of information retrieval from inverted files, and (5) numerical algorithms for solving certain variational problems connected with optimum trajectory and control problems.

Efforts will be made to obtain extensions of Dr. Causey's thesis.[1] Numerical experiments will be conducted on the UNIVAC 1107 in an attempt to find minimum sequences of approximating normal matrices. As a separate investigation, problems of mechanization of the solution of systems of linear algebraic equations with very large number of equations (more than 500) are anticipated.

Infomation retrieval from inverted files is a recurring problem which may involve a very considerable amount of computer time simply due to a very large number of requests. It is proposed to study mathematical problems, applicable to several different computers, involved in computer-mechanized retrieval in the least amount of computer running time.

It is anticipated that some theoretical investigations and numerical experiments will be made in connection with variational problems of current interest to National Aeronautics and Space Administration, especially those being investigated by Dr. Johnson of the Research Institute.

Personnel assisting Dr. Causey in many of these activities will include Mr. Otis Vaughn, Numerical Analyst, who has five years' experience programming computers to solve scientific problems.

Dr. Hsin Chu, Associate Professor of Mathematics, plans to continue and extend the mathmatics research work of the past years. In the coming months emphasis will be placed on the following three subjects:

1. The topological properties of ordinary nonlinear differential equations - Among other things, we intend to study Liapunov stability, asymptotical stability, complete stability, limit cycles, minimal sets, and their possible applications, to control theory. The basic tools will be topological dynamics and differential geometry. Related publications: (1) Hsin Chu, "On Totally Minimal Sets," Proc. Am. Math.

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[1] Causey, Robert L., "On Closest Normal Matrices," Ph. D. Dissertation, Stanford University (May, 1964).

Soc. (1962); (2) Hsin Chu, "Algebraic Topology Criteria for Minimal Sets," Proc. Am. Math Soc. (1962); (3) Hsin Chu, "On Universal Transformation Groups, III," J. Math. (1962); (4) Hsin Chu, "The Fundamental Group and the First Cohomology Group of a Minimal Set," with M. Geraghty, Bull. Am. Math. Soc. (1963); (5) Hsin Chu, "The Automorphisa Group of a Geometric Structure," with S. Kohayeshi, Trans. Am. Math Soc. (1964); (6) Hsin Chu, "On Ultimate Boundedness and Liapunov Stability", (in preparation); (7) Hsin Chu, "A Note on Complete Stability of a Non-linear Control System," (in preparation). Mr. H. C. Wasserman, a Ph.D. candidate at Wesleyan University, will participate in this program during the coming summer.

2. Fixed-point problems in transformation groups - The problem of fixed-points under a group is one of the most important problems in transformation groups. Indeed, it is also an important phenomenon in the physical world. Related publications: (1) Hsin Chu, "A Note on Compact Transformation Groups with a Fixed End Point," (to appear Proc. Am. Math. Soc.); (2) Hsin Chu, "Fixed Points in a Transformation Group," (to appear Pacific J. Math.); (3) Hsin Chu, "Another Note on Transformation Groups With a Fixed End Point," (in preparation); (4) William Gray, "Fixed Points and Transformation Group," Ph. D. thesis, University of Alabama. Mr. Gray will participate in this program this summer. He will finish his Ph.D. program in Mathematics at the University of Alabama this June under Dr. Chu's supervision.

3. The effect of the rotation of earth's atmosphere in the motion of an artificial satellite - In most actual cases of artificial satellite motion, the effect of the rotation of earth's atmosphere is the most important next to the effects of the oblateness and atmospheric drag. This is especially true for a close earth satellite; for example, when the height of its perigee is less than 200 miles. We shall study the problem of attending to oblateness perturbation, the atmospheric drag effect and the rotation of the atmosphere in a single system of equations:

$$\dot{X} = \bar{Y} + Z,$$

where $X = \begin{pmatrix} x_1 \\ x_2 \\ x_3 \end{pmatrix}$, $\bar{Y} = \begin{pmatrix} \frac{\partial W}{\partial x_1} \\ \frac{\partial W}{\partial x_2} \\ \frac{\partial W}{\partial x_3} \end{pmatrix}$ and $Z = \begin{pmatrix} z_1 \\ z_2 \\ z_3 \end{pmatrix}$, W is the

force function which includes the oblateness terms, and z_i represents the atmospheric drag effect. Then

$$z_i = -A(\dot{X}_i + \delta_i)\left[\mu\left(\frac{2}{r} - \frac{1}{a}\right) - 2w(x_1\dot{x}_2 - x_2\dot{x}_1) + w^2(x_1^2 + x_2^2)\right]\exp(-\partial r),$$

where A and are constants, w is the angular velocity of rotation of the atmosphere, r the radius vector, a the instantaneous semi-major axis of the orbit and $\delta_1 = w x_2$, $\delta_2 = w x_1$ and $\delta_3 = 0$.

Miss Pat Lucas will participate in this program. She has her B. S. in Mathematics from the University of Alabama and currently she is a graduate student at the University of Alabama in Huntsville. Related publications: (1) Dirk Bronwer and Gen-ichiro Hori, "Theoretical Evaluation of Atmospheric Drag Effects in the Motion of an Artificial Satellite," The Astro. J. (1961); (2) B. J. Cain, "Determination of Mean Elements for Bronwer's Satellite Theory," The Astro. J. (1962); (3) H. R. Westerman, "Secular Effects of Atmospheric Drag on Satellite Orbit," The Astro J. (1963); (4) W. A. Allen and W. E. Knolle, "Differential Corrections Applied to the Izsak Equations of the Artificial Satellite Motion," The Astro. J. (1964).

N. Structural Mechanics - Dr. G. A. Wempner, Professor of Engineering Mechanics, and Dr. J. T. Oden, Assistant Professor of Engineering Mechanics, expect to initiate work in two theoretical areas.

1. Theories of composite shells - The theory of shells has been studied extensively since the last century. Recent efforts to reduce weight in flight vehicles have drawn attention to sandwich shells and the means to analyze them. Unfortunately, much of this effort has been expended to amend and apply the established theories of one-layer shells. Often the results are questionable and unreliable. Then too, new materials and methods of fabrication have led to composites which lie beyond the existing constitutive equations.

The research is directed toward the rigorous development of the governing equations for complex types of shell structures. These studies will include the effects of large deflections. The results will apply to problems of structural instability, vibration and wave propagation. In order that the studies be of direct practical value the general results will be specialized for particular geometries.

2. The finite element method for continuous media – The finite element method has been applied successfully to linear problems since 1958. Recent attempts to extend the force or stiffness method to nonlinear problems have had limited success. The methods proposed for the analysis of geometrically nonlinear problems fall in two categories: (a) successive corrections of the linearized problem; or (b) formulation of the nonlinear problem which is then solved by successive approximations.

The first technique permits no insight into the nonlinear phenomena and is incapable of detecting characteristics of the behavior of the structure which are peculiar to the nonlinear problem. The second technique has been attempted only recently, and the particular formulations were subject to severe limitations. The proposed research is to develop the finite element method for application to essentially nonlinear problems.

The basic relationships developed in part 1 of the study are to be formulated in terms of discrete variables by the techniques developed in part 2. The research is to culminate with numerical applications to representative problems.

Dr. W. Kubitza, Professor of Engineering Mechanics, plans to extend the optical Moiré method, which has so far been used only for two-dimensional structural elements to three-dimensional structural systems. This method yields

complete information required for the analysis of structural systems such as beams, grid systems, plates of various configuration subjected to different types of loading at much less cost than most other standard experimental methods. The successful completion of such a research effort would open a wide field of application in the investigation of shells.

The development of a structural research laboratory with a broad basis of capabilities will enable the Research Institute to assist in solving structural problems as encountered in launch site equipment and space flight hardware as well as supporting theoretical research in the field of shell analysis, vibrations, flutter, fatigue, etc.

In particular, it is planned to establish dependable methods of investigating the structural behavior in cylindrical and conical shells and of assemblies thereof by reproducing and evaluating on scale models the varying static and dynamic load conditions of missile and spacecraft assemblies in flight.

Further description of the development of the structural mechanics laboratory is given in section O. 4.

O. General Laboratory Development - The addition of the needed laboratory space upon completion of the Research Institute Laboratory-Office building, although a valuable asset, requires the release of time of several staff members to develop the laboratories. The following facilities will receive special attention during the next year:

1. Installation of D. C. Power Source - Dr. Dowdle will provide technical supervision of the installation of a 300-500 KW d-c power source. This power supply, the design of which has recently undergone some revisions, is to supply a large amount of highly-controlled d-c power to the high-temperature, arc-technology, plasma physics, electromagnetics, and laser laboratories. After the final acceptance of the manufacturer's proposal, Dr. Dowdle will be responsible for the supervision of the installation, checkout of the required characteristics, and final acceptance to meet the appropriate laboratory requirements.

2. Anechoic Chamber - Dr. Dowdle will be responsible for the installation of the anechoic chamber to be built in the electromagnetic laboratory. Proposals have been received from manufacturers for its installation, and the proposals are being evaluated. After the chamber has been completed Dr. Dowdle will evaluate its performance within the frequency range for which it was designed.

3. Analytical Laboratory - Dr. Arendale, or a staff member to be employed, will establish an analytical laboratory. An infrared spectrophotometer, an ultraviolet and visible spectrophotometer, an arc spectrograph, and gas chromatograph equipment are now available. An atomic absorption spectrometer and possibly a Raman spectrograph will be added to this equipment. The Research Institute will be in a position to offer analytical services without interfering with the special purpose for which the equipment was obtained.

4. Structural Mechanics Laboratory - Dr. Kubitza has begun to activate the Structural Mechanics Laboratory since assuming his duties February 1, 1965.

The development of this facility will strengthen the research capability and graduate program in the field of theoretical and structural mechanics. Emphasis is to be placed on investigations of phenomena in the field of impact loading, vibration and flutter. It is planned to extend the research capability to include the study of fatigue of structural materials and the effect of design practices on the fatigue life of structures. This structural research laboratory also represents an indispensable tool for checking, confirming, and advancing developments in the field of theoretical mechanics and will allow solving structural problems for which, because of their complex nature, no analytical methods of analysis are presently known.

Work in the next year will be directed toward making the laboratory fully operational at the earliest date. Equipment which has been purchased and is scheduled to arrive during the next months will be set up, checked out, and integrated in an organization which will enable us to carry out model investigations and experimental research in the field of structural mechanics by the following standard experimental methods:

Mechanical Strain Measurements
Brittle Coating
Photoelasticity
Photo Stress (Photoelastic coating technique)
Electrical Strain Gage Technique
Moire Method

The first phase will include the design and construction of some basic structural models which will later be used for instruction purposes.

5. Other Laboratories - Several other special purpose laboratories will be improved as staff and equipment are available. A new staff member is required before further development of the radioisotope laboratory is contemplated. The laboratory has been checked out and radiation counting and alpha, beta and gamma counting equipment has been calibrated.

As soon as personnel are available the equipment will be installed on the antenna range. The space and necessary services have been provided, and most of the equipment has arrived. The microwave and millimeter wave propagation laboratory will be further extended to provide laboratory space for additional thesis work and further research capability.

Programs to be Added During the Next Year:

Several areas of special interest to students and significant in the development of the program of the Research Institute which require the employment of senior staff members during the next year are:

A. Low Density Gas Dynamics - In the past, a program on molecular surface interaction in the free molecule and transition flow region was conducted. This work is important to the study of transfer phenomena in the high altitude aerodynamics. An aspect of this field that will be considered is the aerodynamic contribution due to molecular surface interaction and its effects on space orbit calculation.

B. High-Temperature Thermodynamics and Plasma Dynamics - This work should include theoretical and experimental work in areas of high-temperature thermodynamics, in particular research in thermodynamic properties of, and energy and mass transfer to, ionized gases in plasma generators. A specially designed laboratory is available for this work.

C. Operations Research - An operations research and systems analysis program should be organized.

D. Statistics - Consideration is being given to the development of a research program in mathematical statistics and probability.

E. Celestial Mechanics - Work should be expanded in celestial mechanics. The study of theory of orbits would be an excellent allied development to other space related programs of the Research Institute.

Main Campus

Department of Mathematics

May 5, 1965

Progress Report on, and Proposed Continued Research in, Optimization Techniques as Applied to Space Problems

A. Progress Report

Research on this project was begun in September, 1964. A paper entitled "Application of the Morse Formulation of the Problem of Bolza to Gross' Rendezvous" has been prepared. By "gross" rendezvous is meant interception (one vehicle being flown so that eventually its position coincides with that of a target vehicle) with the added condition that at interception the direction, but not the magnitude, of the interceptor's velocity vector coincides with that of the target. In the situation discussed the target is assumed to be in circular earth orbit; the interceptor is flown optimally (minimum fuel consumption) onto an elliptical earth orbit, whose major axis follows the motion of the target, and coasts thereafter on the ellipse until gross rendezvous is accomplished. Choice of ellipse to be utilized is simultaneously optimized. Over-all optimization is sacrificed to some extent in favor of much increased flexibility including the ability to initiate the maneuver essentially at will, the primary restriction being the necessity of keeping the coasting ellipse outside the earth's atmosphere.

The technique utilized in the scheme described above has been applied also to optimizing a flight from a circular earth orbit onto a hyperbolic earth orbit with a specified asymptote, the vehicle to coast thereafter to escape. The technique permits simultaneous optimization of the choice of hyperbola having the given line in space for asymptote.

Equivalence of the so-called "Slab Conjecture" with the "Annulus Conjecture" for dimensions greater than three was established. The two conjectures are:

(1) The Annulus Conjecture: Let S_1^{n-1}, S_2^{n-1} be two disjoint locally flat n-1 spheres embedded in an n-dimensional sphere S^n. Then the subspace M of S^n bounded by the union of S_1^{n-1} and S_2^{n-1} is homeomorphic to $S^{n-1} \times [0, 1]$.

(2) The Slab Conjecture: Let R_1^{n-1}, R_2^{n-1} be disjoint locally flat n-1 planes embedded as closed subsets of R^n, the euclidian n-dimensional space. Then if M is the subspace of R^n bounded by the union of R_1^{n-1}, and R_2^{n-1}, M is homeomorphic to $R^{n-1} \times [0, 1]$.

C. A. Greathouse in the Bulletin of the American Mathematical Society, Vol. 70, No. 3, May, 1964, proved that (2) implies (1) (and that (2) is false for n=3). The result obtained here is that for $n>3$, (1) implies (2). (The actual validity of neither (1) nor (2) is known except for the lowest dimensions.) Considerable study of other problems proposed last year has taken

place and continues at present.

B. Proposed Continued Research

Work will continue toward clarification of the status of "switching functions" as utilized in calculus of variations optimization programs for space trajectories. A particular problem is one which appears in a NASA paper entitled "Optimal Staging and Sizing for Two Dimensional Vacuum Flight", in which an attempt is made to describe a program utilizing switching functions to solve the problem described in the title. The general work proposed should shed some light on the validity of the process described in the paper, among many other things.

Related to the above is work in general on discontinuous solutions of variational problems. Several authors have written papers on this subject but their approaches put them outside the area of known valid techniques. It is hoped that some of this work can be rescued, perhaps by proper reformulation of the problems, or else by resorting to the Pontryagin Maximum Principle. Since staging problems always involve discontinuities (in mass), this area very much needs investigation if anything approaching optimization is to be obtained.

Other problems as described in last year's proposal still exist and will be investigated as time allows. Although some work on rendezvous has been done, in this area even more is necessary, particularly toward generalizing the class of problems which can be handled.

It is anticipated that a systematic analysis of Russian work on

optimal processes will be soon begun by doctoral level graduate students.

Main Campus

Department of Electrical Engineering May 5, 1965

Progress Report on, and Proposed Research
in, Analysis of Combined Nonlinearities

A. Progress Report

During the Fall Semester of 1964, an exhaustive literature survey was undertaken. Although not all of the material in the articles has been assimilated, it became evident that the problem of combined or multiple nonlinearities has not been given a great deal of attention. Since the original interest of the investigator was to study the application of phase plane and describing function techniques, the problem of studying multiple nonlinearities seemed quite intriguing.

The first nonlinearities which are now being investigated are cascaded hysteresis and saturation which are separated by a linear transfer function. At present analog computer data are being taken which will be used to aid in verifying the results of the analytical investigation. Figure 1 illustrates the problem in block diagram form. The transfer functions G_1, G_2, and G_3 are linear factors.

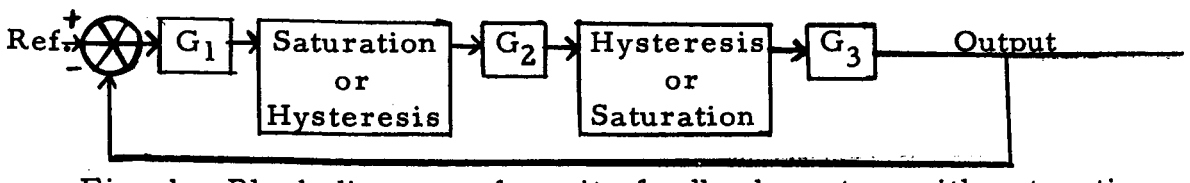


Fig. 1. Block diagram of a unity feedback system with saturation and hysteresis nonlinearities.

G_1 might be an amplifier, G_2 a motor or servovalve, and G_3 a load. The saturation could be caused by the amplifier and the hysteresis by the magnetic circuit of the motor or valve. In an effort start with a simple problem and proceed to more difficult efforts, G_2 is to be considered first a constant, second a gain factor, third a first order lag and fourth a second order lag; G_1 is to remain a constant or a gain factor; G_3 is to be a constant, a pure integration, or a first or second order lag.

There are many ways in which nonlinearities can be combined--both from a theoretical as well as a practical consideration. If the several nonlinearities can be combined into one single effective nonlinearity, then the analysis is relatively straightforward even though perhaps tedious. However, if the nonlinearities are separated or isolated from each other (as often happens) then the analysis may prove difficult or even impossible except by computer techniques.

B. Proposed Research

It is the intention of the investigator to develop methods by which certain combinations of nonlinear and linear transfer functions can be analyzed using phase plane and describing function methods. Several nonlinearities such as backlash, dead zone, coulomb friction, saturation, hysteresis, etc., are to be combined in a variety of configurations and the solutions effected.

During the Spring Semester of 1965, several nonlinearities will

be combined with a linear second order control system and the solution will be analytically determined. If time permits, verification by an analog computer will be given.

During the 1965-66 academic year, additional nonlinearities in various combinations with linear elements will be investigated using analytical and analog techniques. It is hoped that a tabulation of the results will prove useful to other investigators.

Main Campus

Department of Chemistry

May 5, 1965

Progress Report on, and Proposed Continued Research in, Determination of Thermodynamic Functions of Inorganic Solids and the Use of Fused Salts as a Medium for the Preparation of Some Hygroscopic Inorganic Materials

A. Progress Report

Present knowledge concerning solvents and relationships in solvent-solute systems is based largely upon behavior and observation over a rather limited temperature range. The range was usually between $0^{\circ}C$ and the boiling point of the solvent. However, many technical processes involve liquid phase high temperature reactions. Information concerning high temperature reactions is not so well organized as it has been for systems which are employed at ordinary temperatures.

The purpose of the studies reported herein was to synthesize and characterize hygroscopic inorganic halides which are not feasibly obtained from reactions in aqueous media. All starting materials had to be dry and the dry atmosphere for mixing the solid reactants was a dry box which was continuously flushed with a stream of dry air from a nearby Heat-Les dryer.

In its final form, the complete dry box consisted of a paraffin-coated main working box and a port through which entries were made.

The dimensions of the main unit and the port were 37" x 23" x 31" and 24" x 14" x 14", respectively. The back walls and floors of each were plywood, the top and front being of 1/4 inch plexiglas which was secured tightly by screws placed two inches apart. Flexible caulking was used in a further attempt to make all joints air tight. In the plexiglas, places for four gloves were made, three of which were in the main box and one was in the port. The gloves were attached by tension to 3/8 inch aluminum rings mounted around the previously-cut holes in the plexiglas. The doors on each end of the port, one on the outside and the other opening into the box, were of 1/4 inch aluminum. The doors were lined with rubber stripping, mounted with ordinary hinges and fastened with casement fasteners.

Oxide systems have been employed most extensively in syntheses involving fused salts and this research was, therefore, mainly concerned with them. Most recently for example, $VOCl_3$ and $POCl_3$ have been prepared from their respective oxides by chlorinating with aluminum chloride in a LiCl-NaCl-KCl eutectic mixture. This eutectic mixture, composed of equimolar quantities of each salt, melts circa 325°C, thus allowing reasonably low working temperatures. Compounds which can be prepared and isolated conveniently are those which are volatile or are easily sublimed from the reaction mixture.

The reaction vessel consisted of a test tube, 5 cm. in diameter, to which a 24/40 joint was attached. The usual distillation set-up completed the system. The reactants were mixed in the reaction tube inside the dry box and the tube was placed in a Variac-controlled Hevi-Duty furnace and inserted into the system which had been previously flushed with dry nitrogen.

The following reactions were carried out according to the above procedure:

1. $P_2O_5 + LiCl\text{-}NaCl\text{-}KCl \longrightarrow POCl_3 + Li_2O$

   The as yet unpublished work of Drago and Whitten contains a similar reaction: however, they chlorinated the P_2O_5 (in the eutectic mixture) with $AlCl_3$. The $POCl_3$ was characterized by boiling point, refractive index and elemental analysis. Other products were identified in a similar manner.

2. $Na_2SO_4 + PCl_5 + LiCl\text{-}NaCl\text{-}KCl \longrightarrow SOCl_2 + POCl_3$

3. $As_2O_3 + AlCl_3\text{-}NaCl \longrightarrow AsCl_3 + Al_2O_3$
   Yield: 50%

4. $SnO_2 + AlCl_3 + LiCl\text{-}NaCl\text{-}KCl \longrightarrow SnCl_4 + Al_2O_3$
   Yield: 71%

5. $TiO_2 + AlCl_3\text{-}NaCl \longrightarrow TiCl_4 + Al_2O_3$
   eutectic melts at 120°C

   Good yields of $TiCl_4$ from TiO_2 are reported in the literature:

   $$TiO_2 + MgCl_2\text{-}KCl \longrightarrow TiCl_4$$

   The use of the $AlCl_3$-NaCl eutectic greatly lowers the temperature at which $TiCl_4$ may be obtained.

6. $SiO_2 + LiAlH_4 + Al + AlCl3 + LiCl\text{-}NaCl\text{-}KCl \longrightarrow SiH_4$
Yield to be determined

7. $KSCN + AlCl_3 \longrightarrow CS_2$

8. $TiO_2 + AlBr_3\text{-}NaBr \longrightarrow TiBr_4 + Al_2O_3$
Yield: 20%

9. $NaAsO_2 + AlCl_3\text{-}NaCl \longrightarrow AsCl_3 + Al_2O_3 + NaCl$

Some reactions were carried out, as described earlier, in an attempt to establish any correlation or trend existing between them and reactions already useful for the preparation of similar compounds.

Reaction 1 $P_2O_5 + LiCl\text{-}NaCl\text{-}KCl \longrightarrow POCl_3 + Li_2O$

$P_2S_5 + LiCl\text{-}NaCl\text{-}KCl \longrightarrow$ No reaction, i.e., no $PSCl_3$

Reaction in the work of Drago and Whitten

Reaction 2 $V_2O_5 + AlCl_3 + LiCl\text{-}NaCl\text{-}KCl \longrightarrow VOCl_3$

$V_2O_5 + LiCi\text{-}NaCi\text{-}KCl \longrightarrow$ No $VOCl_3$

Also from their work

Reaction 3 $(Na_3PO_3)_x + AlCl_3 + LiCl\text{-}NaCl\text{-}KCl \longrightarrow POCl_3$

$Na_4P_2O_7 + AlCl_3 + LiCl\text{-}NaCl\text{-}KCl \longrightarrow$ No reaction

Reaction 9 was successful for the preparation of $AsCl_3$ from an arsenite in which the arsenic is incorporated in the negative portion of the compound. Proceeding from the encouraging results in chlorinations of this type, the following reactions are to be carried out:

1. $PbSnO_4 + AlCl_3\text{-}NaCl \longrightarrow SnCl_4$?

2. $CuSeO_3 + AlCl_3\text{-}NaCl \longrightarrow SeOCl_2$?

3. $CaTiO_3 + AlCl_3\text{-}NaCl \longrightarrow TiCl_4$?

4. $Na_3P + CH_3Cl + AlCl_3\text{-}NaCl \longrightarrow (CH_3)_3\,P$?

5. $Na_2GeO_3 + AlCl_3\text{-}NaCl \longrightarrow GeCl_4$?

Some thermodynamic functions of sodium bromate, sodium bromide, sodium iodate and sodium iodide were determined. For the determinations a copper block calorimeter was constructed and calibrated electrically. The remainder of the assembly for the determinations consisted of a K-3 L and N potentiometer, G-1 Mueller bridge, platinum resistance thermometer calibrated by National Bureau of Standards, two galvanometers and a Sargent constant temperature bath. All determinations were carried out with the samples in previously calibrated platinum crucibles.

The heat content equations for the compounds were calculated to fit the conditions $H_t - H_{298.16} = a + bT + cT^2 + dT^{-1}$

$a + bT + cT^2 + dT^{-1} = O$ at 298.16^oK

These equations were derived to fit these conditions by the method of least squares using the Univac solid state-80 computer.

Enthalpy measurements of sodium bromate were made in the termperature range $376.9\text{-}601.2^oK$. Measurements were not extended beyond 601.2^oK as the sample decomposed above this temperature. It was shown in a separate experiment that sodium bromide was formed on heating sodium bromate to a temperature

of 660.0°K. Using the data collected a heat content equation was derived for this compound over the range mentioned above. This equation in calories per mole is:

$$H_t - H_{298.16^\circ K} = -3.0485\times10^{4} + 71.263T - 2.6291\times10^{-2}T^{2} + 3.545 + \times10^{6}T^{-1}$$

Enthalpy measurements of a sample of sodium bromide were obtained for both the solid and liquid phases. The derived equation for the solid phase is:

$$H_t - H_{298.16^\circ K} = 1.3726\times10^{4} + 31.001T - 9.7495\times10^{-3}T^{2} + 1.6349\times10^{6}\ T^{-1}$$

The derived equation for the liquid phase is:

$$H_t - H_{298.16^\circ K} = 9.1010\times10^{3} + 3.9841T + 3.3218\times10^{-3}T^{2}$$

The heat of fusion of sodium bromide was found to be 6.24 kilocalories per mole at 1018°K.

From the results of enthalpy measurements of a sample of sodium iodate, the following heat content equation for the solid form was derived:

$$H_t - H_{298.16^\circ K} = 4.6711\times10^{4} + 108.66T - 5.4600\times10^{-2}\ T^{2} + 5.764\times10^{6}T^{-1}$$

Measurements were not extended beyond 656.6°K, because the sample began to decompose above this temperature.

Enthalpy data for sodium iodide were taken in the temperature range 375.5 to 1127°K. The heat of fusion was calculated to be

6.03 kilocalories per mole. The heat content equation for solid sodium iodide is:

$$H_t - H_{298.16^oK} = 5.4210 \times 10^3 + 17.017T - 1.902 \times 10^{-3} T^2 + 1.465 \times 10^5 T^{-1}$$

The heat content equation for liquid sodium iodide was calculated to be:

$$H_t - H_{298.16^oK} = 8.502 \times 10^3 + 6.72T + 8.81 \times 10^{-4} T^2$$

B. Proposed Work

A preliminary study of two other reactions has been made. The following have not been extensively investigated, but do seem to have preparative value:

1. $CrO_3 + PCl_5 \xrightarrow{\text{eutectic}} CrCl_3$

   Chlorinating agents other than PCl_5 have been reacted with CrO_3. In the proposed study a dry, solid state reaction is involved, any excess PCl_5 can be vacuum sublimed. Pure, anhydrous $CrCl_3$ has not been prepared, but by future alterations of conditions we hope to obtain a pure product.

2. $KSCN + AlCl_3 \xrightarrow{\text{eutectic}} CS_2$

   It is also proposed that we continue the study on heat capacities at high temperatures. It is planned to derive heat capacity equations from enthalpy measurements for the halides, bromates, chlorates and iodates of the Group Two elements. We plan to construct an ice calorimeter to aid us in this study. This will give two different calorimeters for the high temperature enthalpy determinations. Also, it is hoped that we will be able to begin construction of a low temperature calorimeter. The addition of this calorimeter would provide adequate equipment for studies down to temperatures of about 60°K. This would give us the necessary data for the calculation of the entropy, as well as other thermodynamic values, for the compounds studied.

Appendix IV
Attachment D

Main Campus

Department of Electrical Engineering May 5, 1965

Progress Report on, and Proposed Continued
Research in, Optimal Control

A. Progress Report

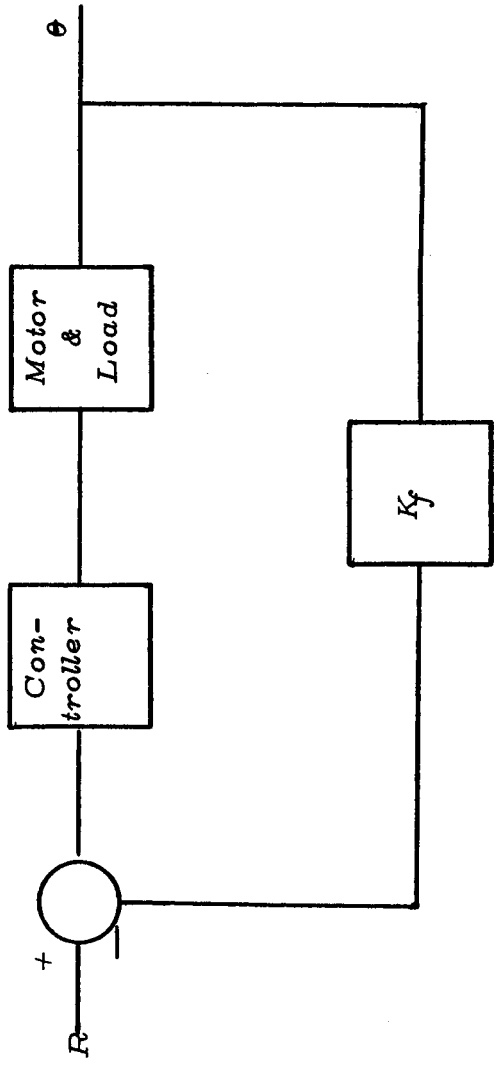
In 1959, Pontryagin published a very interesting result known as maximum principle. Many papers have been published on the bang-bang control system which are in agreement with the results derived by Pontryagin. Also, there are papers dealing with the application of the maximum principle to different optimal control systems.

The purpose of our investigation was to apply maximum principle to specific optimal control systems and co-relate the system initial conditions to the initial conditions of the co-state variables. By optimal control we mean the control of a dynamical system such that the time integral of a function of the state and of the control signal is minimized while the control signal is restricted to be in a specified closed and bounded region.

One system under investigation was the time optimal control of a system characterized by coulomb friction as shown in Figure 1.

Writing motor equations

$$J\ddot{\theta} = kV - B\frac{\dot{\theta}}{|\dot{\theta}|}$$



BLOCK DIAGRAM

Fig. 1

where J is the moment of inertia, θ is the angular shaft rotation and k is a motor constant.

Let $\alpha \triangleq \frac{K}{J}$ and $\beta = \frac{B}{J}$

$$\ddot{\theta} = \alpha V - \beta \operatorname{sign} \dot{\theta}$$

Writing the above in the form

$$\dot{x} = f(x, V, t)$$

$$x_1 \triangleq \theta ; \qquad \dot{x}_1 = x_2 ; \qquad \dot{x}_2 = \alpha V - \beta \operatorname{sign} x_2$$

with the constraint $|V| \leq M$

Minimizing control integral

$$\phi = \int_0^T 1 \cdot dt$$

Including ϕ as an additional state variable

$$x_3 = \int_0^t 1 \cdot d\tau$$

$$\dot{x}_3 = 1$$

The state equations now become

$$\dot{x}_1 = x_2$$

$$\dot{x}_2 = \alpha V - \beta \operatorname{sign} x_2$$

$$\dot{x}_3 = 1$$

Form the Hamiltonian, $H = \sum_{i=1}^{3} p_i \dot{x}_i$

$$H = p_1 x_2 + p_2 (\alpha V - \beta \operatorname{sign} x_2) + p_3 \qquad (1)$$

Now $$\dot{p}_i = -\frac{\partial H}{\partial x_i}, \quad i = 1, \cdots, 3$$

$$\dot{p}_1 = 0$$

$$\dot{p}_2 = -p_1 + p_2 \beta \frac{\partial(\text{sign } x_2)}{\partial x_2}$$

$$\dot{p}_3 = 0$$

Thus $$p_1 = \text{a constant} \triangleq \lambda_1$$

$$p_2 = -p_1 t + \lambda_2$$

$$p_3 = \text{a constant} \qquad (2)$$

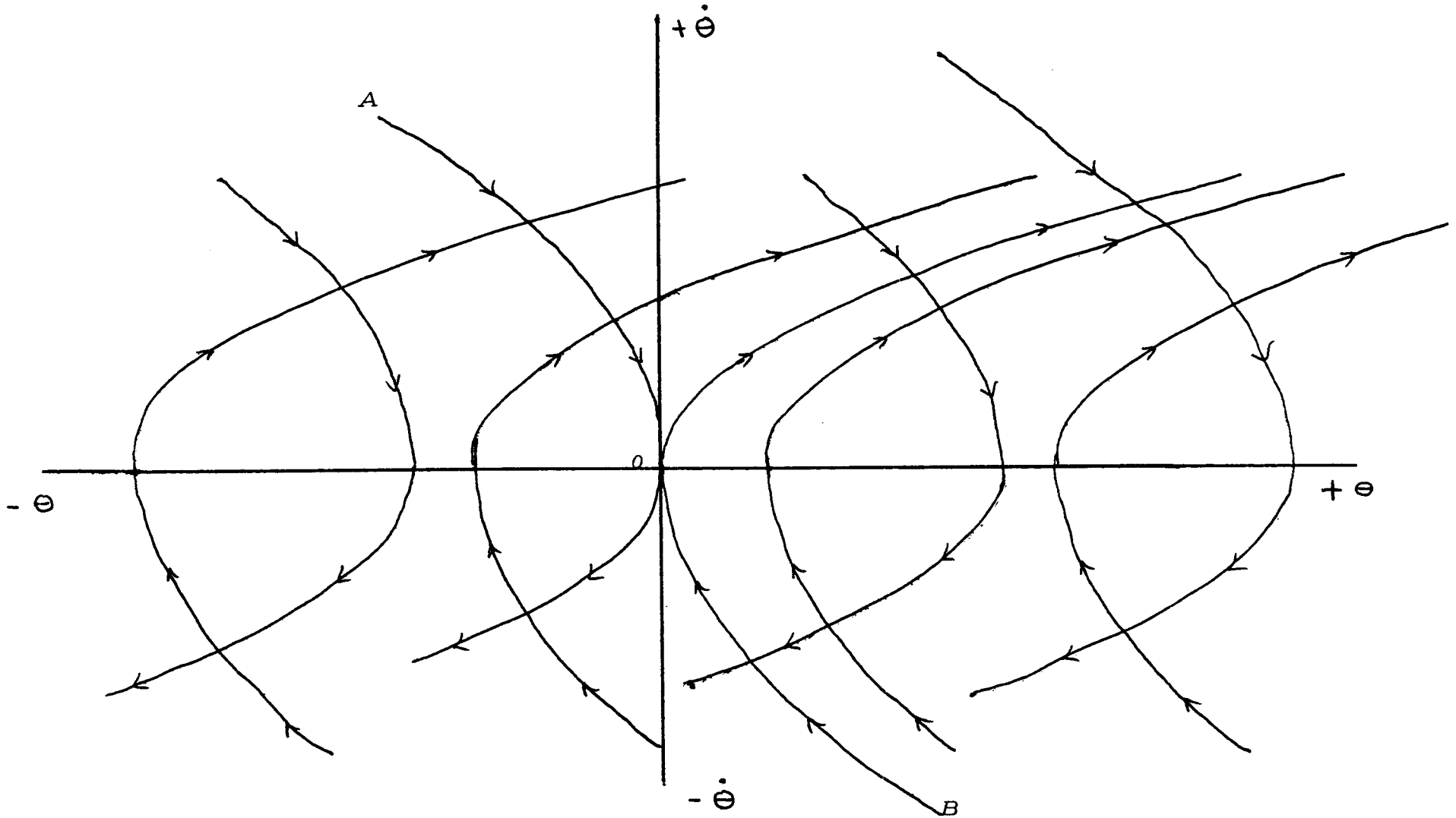
From equation (1) to maximize H with respect to V we must have $|V| = M$ and secondly $V = M\,[\text{sign } p_2]$.

From equation (2) we see that p_2 has the following form

$$p_2 \quad -\lambda_1 t = \lambda_2 \qquad (3)$$

It is obvious that p_2 will change sign as time changes. And according to the maximum principle, when p_2 changes sign, the control vector should change sign. From equation (3) it can be concluded that starting from any initial condition of the system, it takes, at the most, one switching of the control vector to arrive at the final state of the system, in minimum time.

With this condition in mind, the above second order system was simulated on the Analog computer and the phase plane plots were obtained and are shown in Figure 2. From this plot the switching boundary AOB was easily determined. But the object of our study was to arrive at an equation by which the instant of switching could



PHASE PLANE PLOT

Fig. 2

be predetermined. This instant will definitely be the function of the system initial conditions. A set of equations was derived to that effect. For example, the following equation was derived from which the elapsed time could be determined when the system initial conditions are such that we are in the first quadrant on the phase plot.

(4)

$$T = \frac{\dot{\theta}(o)}{\alpha V + \beta} + \frac{\sqrt{\dot{\theta}^2(o) + 2(\alpha V + \beta)} + \theta(o)\sqrt{1/2(\alpha V + \beta)}}{\beta}$$

The instant of switching was computed from the above equation for several initial conditions of the system, and the results were checked with the conventional phase plot methods. As expected, equation (4) yields the time of switching as a function of system initial conditions only.

The controller shown in Figure 1 will be such that it will compute the time according to equation (4) and will reverse the control vector when necessary. Such a controller will take our second order system from one initial condition to another in minimum time.

B. Proposed Continued Research

A second system that is being studied is one characterized by viscous friction. Work is being carried out to build the controller for this system from components rather than using the analog computer. This system is described below.

The torque T developed by a two-phase control motor is described approximately in terms of the voltage V_c applied to the control phase and the angular velocity ω by the equation ($T = KV_c - k\omega$) where K and k are constants. In the case of viscous friction the differential equation describing the motion of the motor is

$$J\ddot{\theta} = KV_c - k\dot{\theta} - B\dot{\theta}$$

where J is total moment of inertia, θ is the angle through which the motor turns, and B is the viscous friction coefficient. The transfer function is

$$\frac{\theta(s)}{V_c(s)} = \frac{K/J}{s(s + \frac{k + B}{J})}$$

It can be shown by the Pontryagin maximum principle that the voltage V_c should be at its largest allowable magnitude at all times in order to move the motor from one rest state to a new rest state in the minimum possible time. Further, only one phase reversal of V_c is necessary.

Employed in a position control system, the motor must have its control phase excited such that rated voltage is always applied but the phase must be reversed at the correct instant of time.

The system under study can be depicted as in Figure 3. A two-phase source is required; one phase is supplied to the reference winding and the second phase is supplied through a transformer and

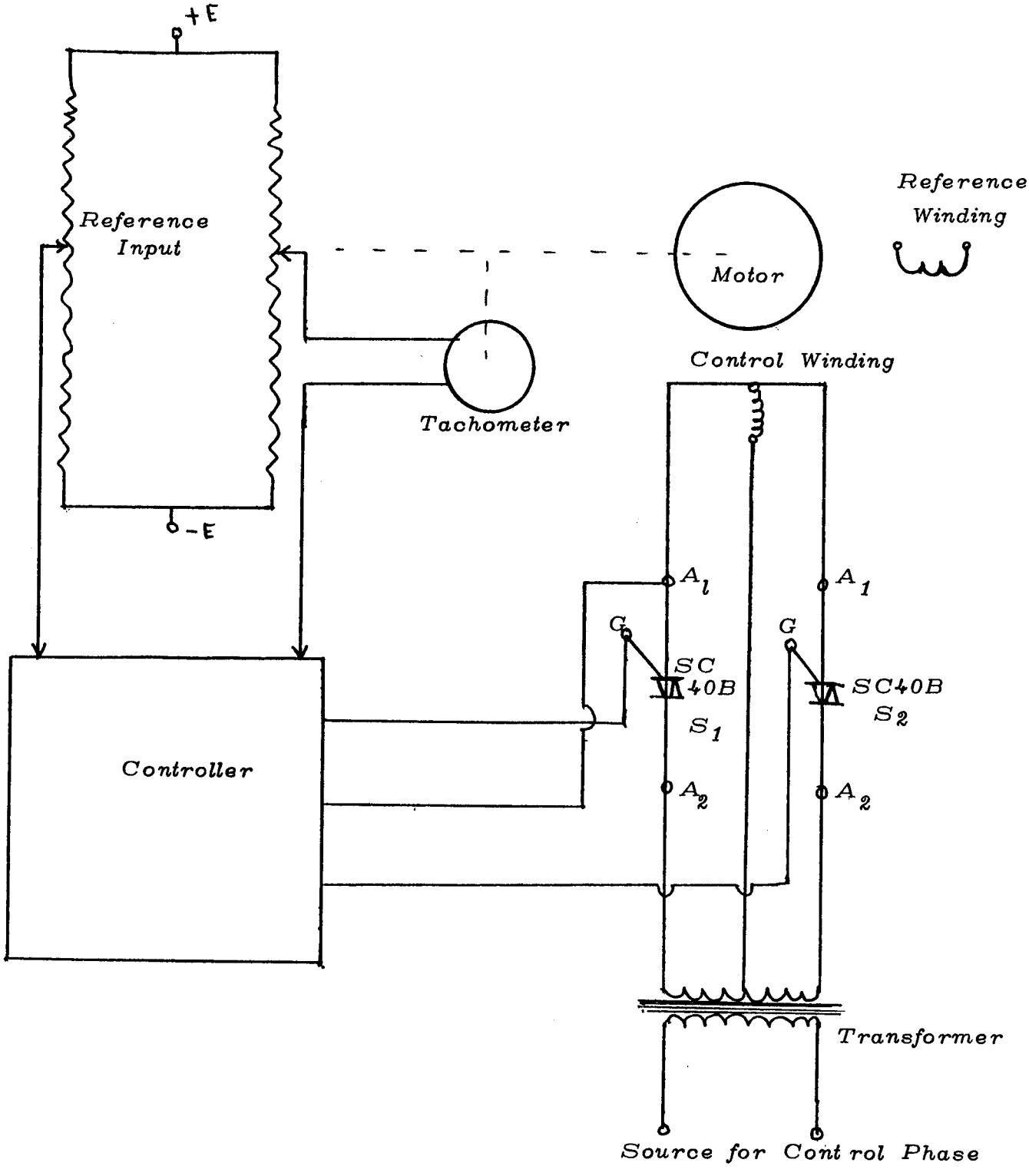


Diagram for Minimum Time Control System Using an AC Control Motor

Fig. 3

control arrangement to the control winding. S_1 and S_2 are gate controlled AC switches, only one of which may be on at any time.

The controller must compare the error and error rate to the optimal switching boundary and generate a gate signal that will turn on either S_1 or S_2 so that the control winding is excited from the source that will yield torque to drive the motor toward zero error and error rate.

The controller consists of a gate driver, nonlinear network for generating the optimal switching boundary, and a comparator whose output will trigger the gate driver. Several schemes for driving the gates have been and are being investigated. Both a modified flip-flop and an operational amplifier used in a comparison circuit are being tested in this application.

Main Campus

Department of Physics

May 5, 1965

Progress Report on Research on Photoelectric Cross-Section Measurements

Conducted by Dr. Ambuj Mukerji during the period September, 1964, through January, 1965

Experience with a previous experiment[1] has indicated that for a precision measurement of the photoelectric coefficient it is a great advantage to use detectors for gamma rays and X rays of very high resolution. Therefore, a major effort was made during this period to study the characteristics of the high resolution solid state detector. A lithium drifted germanium detector of 0.8 mm^2 area and 2 mm depletion depth was used and its performance for the detection of gamma rays of different energies was tested under various conditions. When operated at liquid air temperature, a resolution of < 6 keV fwhm was obtained. The resolution of the detector was found to be very susceptible to extremely small leakage currents of the order of 10^{-9} amps in any of the connectors used.

So far in these experiments the scattered gamma quanta and the X rays emitted due to the photoelectric processes have been measured. A study of the feasibility of measuring the actual photoelectrons emitted

[1] R. M. Dowe, Jr., Attenuation Cross Sections of Thallium at 122 keV, Ph. D. dissertation, University of Alabama (1964).

was studied. The lithium drifted silicon detectors would be ideal for this purpose and the characteristics of these detectors at various temperatures and for different energies of the electrons were studied. An actual measurement of the photoelectric coefficient by this method will be tried in the near future.

This work will be continued by Dr. Mukerji on his own. A report, expected to be completed in the near future, will be forwarded.

Proposed Research on the Restricted 3-Body Problem and the Structure and Behavior of Thin (Passive) Films

The Restricted 3-Body Problem

A. Background

The motion of a sputnik in the gravitational field of two other bodies of finite mass has been the subject of an extended program of computation. The results when the finite masses are equal have already been published by the Danish Royal Academy (Skrifter 2, No. 7, 1964) and those for unequal finite masses will be published in the same journal this summer.

For equal masses, the main symmetric classes of Stromgren were traced continuously from beginning to end, and seven new classes were reported. The representation of a class by means of an eigensurface in (E, F, K) space, where K is the Jacobi integral, was introduced and shown to be particularly useful. Tables and curves were given for more than 800 periodic orbits.

In the second article, for unequal masses, it is demonstrated how

the classes appear, evolve and disappear as the mass-ratio changes from 0 to infinity. Two branches of an eigensurface may move toward each other, touch, and split into two other branches which then move apart. When an eigensurface touches the zero-velocity surface, a change of symmetry (reversal of velocity) occurs, as from (g) class to (f) class. Asymptotic periodic orbits appear and disappear in pairs which necessitates a modification of Stromgren's "Termination Principle." Tables and curves are given for about 1400 periodic orbits, selected from 8000 which were computed.

In addition to the location of periodic orbits, it is important to know how stable they are. Very little has been done on this problem to date, because good criteria for stability have not been known. However, Arnol'd in Moscow and Moser in New York claim to have proved the existence of stability for elliptic fixed points of certain types. They state that there is an invariant domain around such a fixed point, but the size of this domain is not known in general, nor have practical methods been developed as yet for finding it.

B. Proposed Research

During this semester, work is continuing on the invariant domains of the differential equation $(d^2x/dt^2) + px^3 = 0$ by Dr. Bartlett and by a graduate student who remains at the University of Illinois. Work on this equation and extension to the restricted 3-body problem will continue.

The Structure and Behavior of Thin (Passive) Films

A. Background

In a research effort which has been in progress for some years, Dr. Bartlett has investigated the phenomenon of passivity of a metal, important in the theory of corrosion and of electrodeposition. The objectives of this research are:

1. To determine the thickness and the refractive index of passive layers on iron and nickel.
2. To study the electrical behavior of passive nickel in sulphuric acid.
3. To ascertain, both experimentally and theoretically, how the internal charge distribution of a passive layer varies when external conditions are changed.
4. To construct an accurate picture of the mechanisms of formation and removal of the passive layer for iron and nickel.
5. To carry out similar studies for passive chromium.

Research to date indicates (1) that there exists a layer on iron when it is passive, (2) that an electric field drives ions through this layer, (3) that the resistance to the flow of ions is nonohmic, (4) that the thickness of this layer varies linearly with passivating potential from about 8 Å to about 68 Å, and (5) that the interior of the layer is charged when the system is not in the steady state. Two technical reports and one article have been published on the results of this

research.

B. Current Status

Arrangements are being made and equipment is being assembled for transfer of this research from the University of Illinois to the University of Alabama. Meanwhile, research by Mr. Donald DeSmet continues at the University of Illinois. Mr. DeSmet is currently visiting a Canadian laboratory studying the applicability of the ellipsometer to thin film measurements. It is anticipated that this device will be employed in the continuation of this research.

C. Proposed Research

The proposed program is to exploit the method of rapid passivation, which Dr. Bartlett has discovered, to study systematically the electrical behavior of passive nickel, and to compare with passive iron. The general plan of work is:

1. An investigation of the thickness and the refractive index of the passive layer on iron.
2. Determination of the electrical field at the activation barrier for the same systems.
4. Theoretical study of the variation of charge density inside the passive layers and of the rates of formation and removal of these layers.
5. Corresponding studies with passive chromium and aluminum.

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